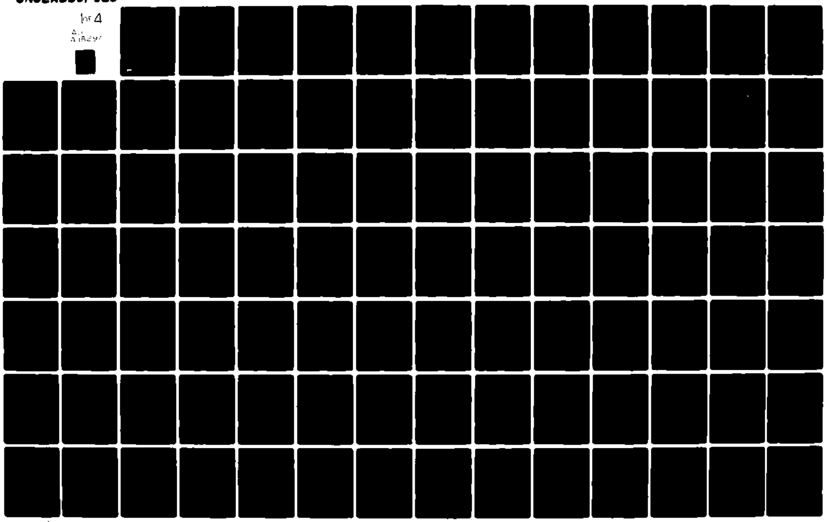
AD-A118 297 SRI INTERNATIONAL MENLO PARK CA F/G 6/4
R&D PLAN FOR ARMY APPLICATIONS OF AI/ROBOTICS.(U)
MAY 82 D R BROWN, D V FOWLER, D J FRIE DAAK70-81-C-0250

UNCLASSIFIED ETL-0296 NL

1 of 4
AD A118297



AD A118297

ETL-0296

R&D PLAN FOR ARMY APPLICATIONS OF AI/ROBOTICS

Final Report

May 1982

By: David R. Brown, Project Leader
Darrell V. Fowler
David J. Frie
William M. Hadly
Joan C. Introne
William T. Park
Ann E. Robinson
William Schubert

Prepared for:

U.S. Army Engineer Topographic Laboratories
Fort Belvoir, Virginia 22060

Contract No. DAAK70-81-C-0250
SRI Project 3736

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

SRI International
333 Ravenswood Avenue
Menlo Park, California 94025
(415) 326-6200
Cable: SRI INTL MPK
TWX: 910-373-2046

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ETL-0296	2. GOVT ACCESSION NO. AD-A118297	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) R&D PLAN FOR ARMY APPLICATIONS OF AI/ROBOTICS		5. TYPE OF REPORT & PERIOD COVERED Final Report
		6. PERFORMING ORG. REPORT NUMBER SRI Project 3736
7. AUTHOR(s) David R. Brown, Darrell V. Fowler, David J. Frie, William M. Hadly, Joan C. Introne William T. Park, Ann E. Robinson, William Schubert		8. CONTRACT OR GRANT NUMBER(s) DAAK70-81-C-0250
9. PERFORMING ORGANIZATION NAME AND ADDRESS SRI International 333 Ravenswood Avenue Menlo Park, California 94025		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Engineer Topographic Laboratories Fort Belvoir, Virginia 22060		12. REPORT DATE May 1982
		13. NUMBER OF PAGES 324
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Artificial intelligence
Research management
Robots
Tactical warfare

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

One hundred applications of artificial-intelligence technology and robotics in Army combat and combat support that may be possible and worthwhile are identified. These possible applications have been divided into ten categories, and one example in each category has been examined in detail. Research and development plans have been developed showing the basic and applied research that would be needed to make the applications possible. Although the number of possible applications is large, the number of key technology elements is

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (continued)

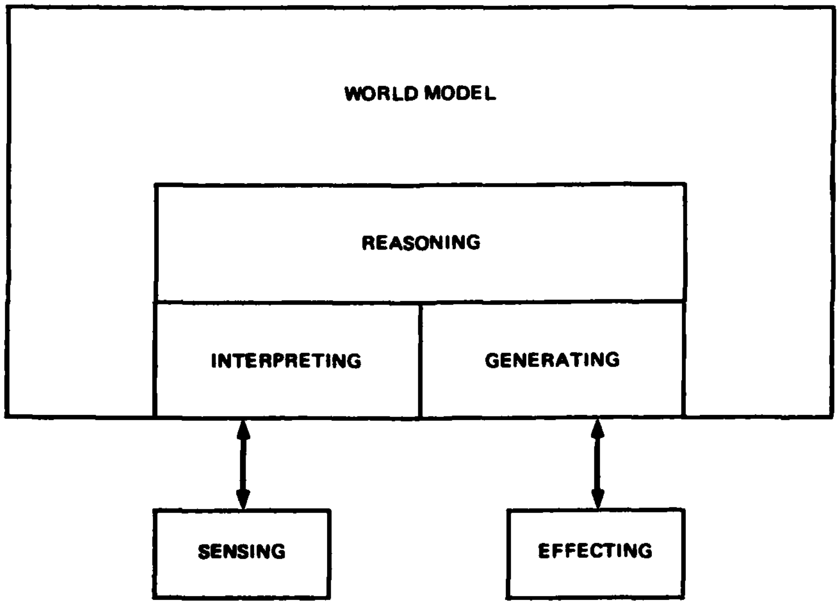
relatively small, and many of the same technology elements are required in many different applications.

EXECUTIVE SUMMARY

The study reported here is intended to help shape the Army's research and development plan for applications of artificial intelligence (AI) and robotics in combat and combat support.

An intelligent robot should be able to think, sense, and effect. Thinking is primarily a brain function. Sensing (seeing and touching) and effecting (moving and manipulating) are primarily body functions. The thinking function executed by a computer is the domain of artificial intelligence. Sensing and effecting are based on physics, mechanical engineering, electrical engineering, and computer science. Planning and execution of tasks entail both brain and body functions and are concerns of both artificial intelligence and robotics. No attempt is made in this report to distinguish between artificial intelligence and robotics; instead, a unified model that encompasses both is proposed.

The unified model of AI/robotics is illustrated below.



A UNIFIED MODEL OF ARTIFICIAL INTELLIGENCE AND ROBOTICS

The approach to identification of potential applications of AI/robotics in Army combat and combat support is comprehensive and methodological. Five tasks were involved in the approach.

(1) Data Collection--Identifying, assembling, and/or extracting pertinent studies and doctrinal/concept publications, and reviewing current Army thinking through contact with major Army agencies (Section 2.1).

(2) Application Concept Derivations--Analyzing combat/combat support from six distinctly different viewpoints: threats, units, equipment, functions, environment, and personnel (Section 2.2).

(3) Technological Possibilities Appraisal--Appraising feasibility of concepts (based on Section 3).

(4) Synthesis of Application Categories--Synthesizing analyzed information on application concepts and technical possibilities into meaningful categories for research (Section 4.1).

(5) Detailed Application Examples and Design Criteria--Preparing descriptions of potential examples illustrating each category of application, and defining criteria to guide research activities in each of the application categories (Section 4.2).

This approach resulted in identification of 100 specific concepts for AI/robotics combat/combat-support systems. Because of this large number of concepts, the concepts were used as a basis for defining ten broad categories of applications. The application categories were selected according to three criteria:

* Technological Similarity--Concepts in a group require advances in similar technical areas of AI/robotics.
* Military Use--Each category should pertain to a recognizable element of military activities.
* Comprehensiveness--The categories should encompass all potential combat/combat-support AI/robotics applications, as illustrated by the derived concepts.

The ten categories thus defined are:

(1) Human/Equipment Interface Aids

(2) Planning and Monitoring Aids

(3) Expert Advisors

(4) Data Assimilation and Access Aids

(5) Handling Support Systems

(6) Support Systems

(7) Situation Assessment Systems

(8) System Controllers

(9) Weapons

(10) Information Collectors

To develop and demonstrate objectives, approaches, and methodologies for AI/robotics, an example was chosen from each of the ten categories for further study. The examples chosen were:

Category	Example
1. Human/Equipment Interface Aids	Division Commander's Quick Data-Access System
2. Planning and Monitoring Aids	Brigade Mission Planning Aid
3. Expert Advisors	Emergency Repair and Maintenance Advisor
4. Data Assimilation and Access Aids	Interrogation Support System
5. Handling Support Systems	Tank Ammunition Handler
6. Support Systems	Mine Clearer
7. Situation Assessment Systems	Tactical Threat Projection System
8. System Controllers	Safe Return Controller
9. Weapons	Light Fighting Sentry
10. Information Collectors	River Reconnaissance System

Each of the ten examples is described in detail, including need, employment concept, capabilities, organizational distribution, physical design, technology gaps, and evolutionary versions. The technology gaps provide the basis for the research plan.

The recommended research plan consists of fundamental research, specific research tasks, and system considerations. Included in the research plan for AI/robotics are five fundamental research areas, 97 specific research topics, and eight system considerations. Research on some supporting technologies is required.

Most potential applications will require advancement of the technology base (6.1 and 6.2) before advanced development (6.3) of the

applications can be started. With the capabilities ascribed to the ten examples, the study estimated that development could be started on only four during the next ten years. Two of the ten examples would require deferral of development until the year 2000.

However, early starts for development of AI/robotics applications may be possible if applications with less capability are developed. The study identified four of the ten candidate applications as examples that could be developed now, with essentially today's technology. These candidate applications are:

Mine Clearer
Brigade Mission Planning Aid
Tank Ammunition Handler
Division Commander's Quick Data-Access System

These applications also rank favorably when benefits, costs, and risks are considered. However, no evaluation was attempted of all of the 100 specific AI/robotics concepts as candidates for development with today's technology.

Successful future applications of AI/robotics will require that research plans include system considerations, such as feasibility studies, development tools, system integration, and modularity. Both hardware and software modules that would be common for a number of applications appear to be possible. Much of the evolution of AI/robotics systems should be possible by means of module replacement, especially by the upgrading of software modules.

Countermeasures and counter-countermeasures should also be included in the research plan as system considerations.

Although some of the ten examples that were studied in detail are long range, such as the Light Fighting Sentry and River Reconnaissance System, the research that would make these examples possible is necessary in order to realize important functions that will be vital for many Army applications in the future.

Conclusions

To summarize the foregoing discussion, the conclusions of the study of an R&D plan for Army applications of AI/robotics are as follows:

(1) AI/robotics will significantly enhance the capabilities of the Army.

(2) A unified model of artificial intelligence and robotics can be postulated and successfully applied for Army R&D planning in AI/robotics.

(3) The number of potential applications of AI/robotics in Army combat and combat support is large. One hundred concepts were identified.

(4) The 100 concepts can be divided into ten categories of applications, based primarily on combat and combat-support functions. These categories are:
   - Human/Equipment Interface Aids
   - Planning and Monitoring Aids
   - Expert Advisors
   - Data Assimilation and Access Aids
   - Handling Support Systems
   - Support Systems
   - Situation Assessment Systems
   - System Controllers
   - Weapons
   - Information Collectors

(5) There are a number of gaps between the current state-of-the-art in AI/robotics and the technology required to realize the application. These technology gaps, or research tasks, provide a basis for a research plan that supports the development of the exemplary concepts and other applications of AI/robotics in Army combat and combat support.

(6) The required research consists of fundamental research, specific research tasks, and system considerations. The research can be organized into five fundamental research topics, 97 specific research topics (in sensing, interpreting, reasoning, generating, and effecting), and eight system considerations. In addition, research on some support technologies is required.

(7) Most of the research tasks support multiple applications, and several common system modules could be identified.

(8) Additional study and evaluation of the 100 concepts are needed. Such studies are needed primarily to define better objective applications of AI/robotics to Army combat and combat support, and secondarily to improve the

definition of the research plan presented here. The plan includes research to obtain information required to make future decisions about research priorities and application objectives.

(9) Most potential applications will require advancement of the technology base (6.1 and 6.2) before advanced development (6.3) of the applications can be started. With the capabilities ascribed to the ten examples, the study estimated that development could be started on only four during the next ten years. Two examples would require deferrment of development until the year 2000.

(10) Early starts for development of AI/robotics applications are possible if applications with less capability, evolutionary versions of the objective applications, are developed. The study identified four of the ten examples as candidate applications that could be developed now, without advancement of the technology base. These candidate applications are:

Mine Clearer
Brigade Mission Planning Aid
Tank Ammunition Handler
Division Commander's Quick Data-Access System

(11) Successful future applications of AI/robotics will require the inclusion of system considerations in research plans, such as feasibility studies, development tools, system integration, and modularity. Both hardware and software modules that would be common for a number of applications appear to be possible. Much of the evolution of AI/robotics systems should be possible by means of module replacement, especially by the upgrading of software modules.

(12) Countermeasures and counter-countermeasures should also be included in the research plan as system considerations.

(13) Although some of the ten examples that were studied in detail are long range, such as the Light Fighting Sentry and River Reconnaissance System, the research that would make these examples possible should be supported because it addresses important functions such as mobility, navigation, and identification of targets, that will be vital for many Army applications in the future.

Recommendations

In accordance with the findings of this study, the following recommendations are made:

Recommendations

In accordance with the findings of this study, the following recommendations are made:

(1) Advance the state-of-the-art in AI/robotics and develop a technology base for AI/robotics through:

Fundamental research	5 tasks
Specific research tasks:	
Sensing	6 tasks
Effecting	5 tasks
Manipulators	4 tasks
Mobility control	7 tasks
Language generation	10 tasks
Computational vision	12 tasks
Language interpretation	8 tasks
Information assimilation	6 tasks
Expert systems	13 tasks
Action planning	16 tasks
Situation monitoring	10 tasks
Supporting technologies	7 tasks
System considerations	8 tasks

(2) Establish priorities for concept development based on the state-of-the-art assessment for each concept, military needs, risks, costs, and estimated dates for completion of prototype development.

(3) The development of evolutionary versions of the following candidate concepts could be initiated with little or no advancement of the present state-of-the-art. The candidate concepts are:

Mine Clearer
Brigade Mission Planning Aid
Tank Ammunition Handler
Division Commander's Quick Data-Access System

Development of the Mine Clearer has already been started by the Army. Plans for it need to be reviewed in the context of the Mine Clearer described in this report. Research tasks that support the Mine Clearer, for navigation and for mine location, should be given priority.

Research that supports the other three candidate applications, for which the development of evolutionary versions could be started now, should receive special attention.

(4) System considerations are important and should be included in the research plan, including system integration and modularity. Hardware and software modules for AI/robotics applications could be used to

upgrade evolutionary versions and to support multiple applications.

PREFACE

This document was prepared under Contract No. DAAK70-81-C-0250 for the U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia 22060 by SRI International, Menlo Park, California 94025. The Contracting Officer's Representative was Dr. Robert D. Leighty.

CONTENTS

APPENDICES

LIST OF ILLUSTRATIONS

LIST OF TABLES

1. INTRODUCTION

The objective of the work reported here is a plan for research and development in artificial intelligence and robotics for applications in Army combat and combat support. The plan is for the period extending to the year 2000, and includes details for the years 1984 to 1990.

Long-range objectives have been chosen to motivate the R&D plan. This approach, rather than one focused on short-range goals, has been taken because many of the potential applications of artificial intelligence (AI) and robotics are conceptually different from present Army combat and combat support equipment or systems, and they will never be possible unless the necessary advances in the technology base are recognized and supported.

The scope of the study leading to the R&D plan is comprehensive, including nearly all aspects of Army combat and combat support. Many sources of information and ideas were used in preparing the plan, including DARCOM and TRADOC. However, the opinions and recommendations contained in this report are those of its authors, who have drawn heavily on the ideas of others, both in the Army and among its contractors.

Although the scope of the study is comprehensive, the work has not been exhaustive. The future holds too many possibilities for applications of AI/robotics for all of them to have been investigated. For that reason, some examples of future applications were chosen for detailed study--examples that are believed to be representative and valid for the motivation of R&D. The choice of these examples should not be interpreted as a forecast or recommendation that the specific items should be developed.

A few of the examples are short range and can be developed with little or no advancement of the technology base. However, most have deliberately been chosen to be long range in order to identify a broad spectrum of research needs.

Since many of the examples are long range and are described in some detail, the authors have had to speculate about the future progress of research; such speculation is risky and controversial. However, technology forecasting is a necessary part of the planning process. Throughout the report, an attempt has been made to state the risks along with the forecasts, so that the reader will not be misled.

2. IDENTIFYING ARMY APPLICATIONS

As an overall technical approach to this project, SRI recognized that potential Army applications should be the foundation for a research plan. These applications provide the link between Army needs (insofar as they can be defined in advance) and the technological opportunities offered by progress in AI/robotics.

In accordance with the contract scope, we restricted attention to applications in the combat and combat-support areas, even though it was recognized that there are many potential AI/robotics applications in other aspects of Army operations such as a combat service support.

The main objective of the effort to identify applications was a well documented, comprehensive, and appropriately organized definition of specific areas in which progress in AI/robotics would be both highly beneficial to the Army, and technically feasible.

SRI followed a top-down approach to the definition of applications, deriving application needs from a careful examination of Army combat and combat-support concepts, seasoned with an understanding of the technological opportunities in the AI/robotics field. The overall structure of the approach involved five elements, which are explained in subsequent report sections. They are:

(1) Data Collection--Identifying, assembling, and/or extracting pertinent studies and doctrinal/concept publications, and reviewing current Army thinking through contact with major Army agencies (Section 2.1).

(2) Application Concept Derivations--Analyzing combat/combat-support from six distinctly different viewpoints: threats, units, equipment, functions, and personnel environment (Section 2.2).

(3) Technological Possibilities Appraisal--Appraising feasibility of concepts (Section 3).

(4) Synthesis of Application Categories--Synthesizing analyzed information on application concepts and technical possibilities into meaningful categories for research (Section 4.1).

(5) Detailed Application Examples and Design Criteria--Preparing descriptions of potential examples illustrating each category of application, and defining criteria to guide research activities in each of the application categories (Section 4.2).

2.1. Data Collection

The data-collection effort focused on identifying and assembling pertinent studies, publications, and informal information sources. The major elements of this effort were:

(1) Assembly of pertinent prior studies and doctrinal/concept publications bearing on combat/combat-support and AI/robotics applications.

(2) On-line and manual data searches of major data bases for pertinent materials.

(3) Informal consultations with major Army agencies to identify recent or ongoing works pertinent to this area.

At present, the Army prepares formal Mission Area Analyses as its method of considering future needs. These studies were recognized as a key authoritative source of information. As a result of difficulties encountered in acquiring these studies (many were still in the preparation and approval stage), they could not be used. However, the research team was able to discuss most of the mission areas informally with Army agencies, and also considered many other recent studies on Army needs. The major studies and documents considered were:

* Air-Land Battle 2000 and Annexes
* Prolonged Combat Phase IV
* Soviet/US Capabilities to Conduct Continuous Combat Operations
* Continuous Land Combat
* Army Science and Technology Objectives Guide, FY 80
* DARCOM Long Range R&D Plan
* AI/Robotics Applications to EW
* Army C^2 Master Plan

* C^3 Countermeasures
* Mission Area Structure for R&D Acquisition Activities
* Automated Weapons in Conventional/Guerrilla Warfare
* Advanced Reconnaissance Systems Study
* New Equipment, Personnel Monitoring
* Combat Engineer Systems Handbook
* Soldier Machine Interface Study
* Army Field Manuals

As part of the effort, major data bases were searched for prior studies on Army AI/robotics applications. Automated searches were conducted of DTIC, NTIS, INSPEC, ORBIT, and RLIN. Manual searches of TABS, the SRI library and the Stanford University library were also conducted. As a result, 325 prior (since 1976) studies relating to possible Army applications were identified. The nature of these studies is indicated in Table 1.

Table 1

PRIOR RELATED AI/ROBOTIC APPLICATION STUDIES

Areas of Application	Number
Weapons	29
Vehicles	21
Explosives, Mines	12
Remote Control, RPVs, Drones	37
Reconnaissance, Deception, Surveillance, Intelligence and EW	43
Terrain, Environment, Obstacle Avoidance	39
Target Recognition, Tracking and Engagement	69
Man-Machine Interface	8
Imaging, Optics, Radar and Video	31
C^3	10
Planning, Decision Aids	24

The great majority of the studies were related to artificial intelligence. Most of the work was exploratory in nature, and no indication of adopted, fielded AI/robotics systems was found. (A

separate bibliography of these studies was prepared during the course of the work.)

The data collection included informal contacts and discussions with representatives of the organizations shown in Table 2.

Table 2

INFORMATION SOURCES

Primary Agencies
DARCOM--Army Materiel Development and Readiness Command
TRADOC--Army Training and Doctrine Command
DCSPER--Deputy Chief of Staff, Personnel (Army)
MEDRADCOM--Mobility Equipment Research and Development Command (Army)
ETL--Engineer Topographic Laboratories

Other Agencies
DCSOPS--Deputy Chief of Staff for Operations and Plans (Army)
DCSRDA--Deputy Chief of Staff for Research, Development, and Acquisition (Army)
OCE--Office, Chief of Engineers
HTTG--High Technology Test Group
DNA--Defense Nuclear Agency

Contractors
Honeywell Systems and Research Center
Hughes Research Laboratories
Lockheed Missiles and Space Company
Martin Marietta Corporation
The Rand Corporation

These contacts provided insights into Army problems and needs, and numerous ideas on potential applications. Within DARCOM, discussions with the U.S. Army Human Engineering Laboratory were particularly helpful. Within TRADOC, the U.S. Army Soldier Support Center provided many insights into future Army problems and needs.

As stated before, although the organizations listed in Table 2 provided cooperation and assistance in this study, none of the views or applications outlined in this study should be interpreted as bearing approval of the cognizant Army agencies. They are based solely on the informed analysis and judgment of the SRI research team.

2.2. Analysis

In order to obtain a broad and comprehensive perspective of potential AI/robotics applications, SRI undertook six separate analyses, which considered combat and combat support from different viewpoints. These analyses were:

(1) Threat Analysis--An examination of threats to identify particular aspects of operation that might influence U.S. AI/robotics applications, including potential enemy developments in AI/robotics.

(2) Units Analysis--An examination of the mission, functions, operations, and doctrine of combat/combat-support units.

(3) Equipment Analysis--An examination of the weapon systems and other major equipment used for combat/combat-support.

(4) Functions Analysis--An examination of the major functions involved in combat/combat-support operations.

(5) Environment Analysis--An examination of environmental factors pertaining to possible combat/combat-support operations to identify specific problems that affect AI/robotics applications.

(6) Personnel Analysis--An examination of qualitative and quantitative personnel problems.

The approaches to these analyses were generally similar. They involved reviewing assembled data, identifying and organizing information pertinent to the needs for AI/robotics (from the particular viewpoint involved), considering the identified problems, and suggesting possible AI/robotics approaches to improvement in problem areas. The analyses are explained in the following subsections. The AI/robotic concepts suggested by the analyses are described in more detail in Appendix A.

Progress in these analyses provided feedback for various aspects of the data-collection effort, particularly consultation with Army agencies. The analyses also involved a close interplay with the technology appraisals discussed in Section 3 to assure that opportunities were recognized, and infeasible concepts were not pursued.

In order to focus the effort on combat and combat support, some clear division of the entire field of potential Army applications along

these lines was needed. Current Army thinking divides this area into four sub-areas: combat (C), combat support (CS), combat service support (CSS), and manufacturing methods and technology (MM&T).

The area that is most closely allied with current AI/robotics industry efforts is MM&T. The application concepts falling into this area are generally quite recognizable due to their setting in manufacturing operations, although there may be some overlap with combat service support in major depot repair/overhaul operations.

On the other hand, it was found that the C/CS/CSS distinction does not provide a precise basis for organizing applications. As is indicated in the following discussions of the analyses, some items may appear to be C/CS when viewed from one viewpoint, and to be CSS from another. In view of this, an open approach was taken--accepting concepts for inclusion in C/CS even though they might appear to be CSS from some viewpoint. The overall definitions adopted to guide this selection were:

* Combat--Direct fighting with the enemy for the purpose of destroying personnel and equipment, and seizing or holding territory.
* Combat Support--Providing operational assistance to combat forces.
* Combat Service Support--Efforts that provide services (supply, maintenance, medical, administration, etc.) in support of combat and combat-support activities.

2.2.1. Threat

A great deal of US/NATO doctrine and tactics is predicated on analyses of the Soviet/Warsaw Pact threat. Therefore, it is imperative to consider at least a portion of the threat as it

* Relates to AI/robotics
* Provides an impetus to U.S. military planners.

It is difficult to characterize various aspects of the threat in isolation due to the multifaceted nature of the threat itself, and the interrelationships between doctrine and tactics. For the purpose of

this analysis, we have selected six critical threat ingredients that have implications for the field of AI/robotics. By no means is the list complete; however, it does serve to delineate a combination of Soviet/Warsaw Pact doctrine/tactics that will probably have the most lethal impact on U.S. Army combat/combat-support power. We also explored briefly the expanding Soviet R&D emphasis in the AI/robotics areas. The threat as discussed in this section is predicated on those scenarios depicting a US/NATO, Soviet/Warsaw Pact confrontation in West Germany; however, similar considerations apply to other potential conflicts with forces that follow Soviet doctrine and tactics.

2.2.1.1. Momentum and Continuous Combat

Threat forces have two primary objectives: to achieve momentum and to maintain continuous combat. According to Soviet doctrine, momentum is obtained with mass times velocity, and continuous combat is achieved by the echelonment of forces. The essence of the Soviet offensive (particularly emphasized in surprise scenarios) is speed. The Soviet propensity for mass has changed little over the years, and the technology revolution has done little to change that doctrine. For example, the Soviet Union produces on the order of 1000 units of artillery and approximately 3000 tanks per year; there are more people in the Soviet Air Defense organization than in the entire U.S. Air Force.

The fact that the Blue forces are outnumbered in many tactical areas, has long been acknowledged by U.S. military planners. In most wars, adequate masses of soldiers and materiel with sufficient technology can usually overcome high technology forces of insufficient quantity. Technology, in and of itself, has rarely been the major component in achieving military victories. It has been the innovative use of that technology by imaginative military commanders that achieved extraordinary success over enemies who remained dogmatic in their thinking. Many have been quoted as saying that the Soviet military system "stifles initiative," but it would be wise to remember that

Soviet Army officers, as "elite" party members, are permitted to exercise some degree of initiative and imagination to achieve a goal.

One of the roles that AI/robotics technology could fill is not necessarily to add sophistication to an increasingly complex battlefield, but rather to provide an interface to permit the time and means for innovative thinking and force agility. Table 3 illustrates six current and future areas of threat doctrine/tactics with implications for AI/robotics, and lists AI/robotics concepts that could contribute to countering the threat. The application concepts are described in more detail in Appendix A.

Table 3

CURRENT & FUTURE THREAT DOCTRINE/TACTICS
WITH IMPLICATIONS FOR AI/ROBOTICS

Threat	Problems and Implications for AI/Robotics	Application Concepts
Momentum doctrine mass x velocity	Force multiplier	Close Air-Defense Sentry
Continuous combat capability/ echelonment	2nd echelon information Probable enemy courses of action	Tactical Reconnaissance Robot Tactical Threat-Projection System
C^3 counter-measures/EW threat techniques, high frequency radars	Rapid detection of deception use Signal sorting/ jamming needs	Deception Identification System Portable Deception System Remote Adaptive Jamming System
NBC capability	Advance warning	NBC Sentry
PGM/IFF	Countermeasures	Armor Hit-Avoidance System IFF Module
Probable threat, development of AI/robotics military applications	Unknown	Unknown

AI/robotics has the potential to create a force-multiplier effect. For example, systems incorporating AI/robotics could increase the ability to allocate and concentrate firepower on rapidly advancing enemy forces. The concept of the Close Air-Defense Sentry is an example in which a system would have the capability of automatic target acquisition and engagement. Soviet air defenses are continuing to grow at a prolific rate. The relatively recent emphasis by the Soviets on fielding tactical air defense systems that exhibit roughly the same

degree of mobility as the tactical forces they accompany, goes hand-in-hand with their doctrine of momentum and continuous combat.

The Soviet doctrine of continuous combat is achieved by the organization of forces into echelons. A Soviet division commander controls his units directly behind the first echelon battalions with one-half to two-thirds his maneuver forces and most of the supporting artillery in the first echelon of the attacking organizations. The balance of the force is in the second echelon. In this manner, the intensity of the offensive can be maintained at the points of contact along the main thrust of the battle. When exhausted, a Soviet unit is replaced in kind by a fresh unit. In the current U.S. concept, each division is, for the most part, autonomous and self-sustaining; losses in men and materiel are made up from replacements/reinforcements.

Because of the increasing dependence on electronics technology and the lethality of modern weapons, maintaining the pace of modern combat will require, among many other essential factors, rapid and accurate information on enemy disposition. In this area, AI/robotics concepts such as a Tactical Reconnaissance Robot and a Tactical Threat-Projection System can serve to assist in real-time intelligence gathering, planning, and decision options.

2.2.1.2. C^3 Countermeasures Techniques and EW Threat

The concept of C^3 countermeasures maintains that modern military forces have reached such a state of dependency on electronic systems that sufficient disruption will significantly reduce combat effectiveness. Due to this dependency and the crucial role that electronics plays on the battlefield, threat EW becomes even more pervasive and seriously affects our ability to maneuver and deliver fire. While Soviet emitters have been termed as lacking in sophistication, they are obviously present in sufficient numbers and with considerable redundancy to present a highly effective combat power. This very reliance on electronics has become an exploitable vulnerability for both the Red and Blue forces.

The key to most threat systems lies in their sensors, which are required for surveillance, acquisition, tracking, and guidance where a high degree of accuracy is a necessity. Although RF radar is still the primary means for accomplishing these functions, great technological strides are being made by both the Red and Blue R&D communities in infrared, electro-optical and visual sensor technologies. In the RF radar area, computer (processor) augmentation is making newer Soviet radars more difficult to jam. The Soviet trend is towards higher frequency radars and the frequency spectrum of Soviet threat radars is, in itself, virtually a countermeasure to many jamming systems. Each new, and higher frequency selected, makes the jammer's task more difficult. Jammers can easily become targets due to the large amount of power they put out. In addition to questions of whether or not to employ countermeasures such as jamming (when the Soviet systems have been detected at the same frequency as U.S. emitters), questions regarding what to jam, and when to do it in order to disrupt or destroy Soviet combat effectiveness are important. AI/robotics technology has applications in the above-described areas.

Two important EW considerations are: (1) the ability to recognize rapidly and take action when threat countermeasures are being employed by the enemy, and (2) the ability to be able to sort signals efficiently, prioritizing targets in a crowded electromagnetic spectrum. The concept of a Remote Adaptive Jamming System would be designed to assist in the location and identification of priority threat emitters, with the added capability of being able to formulate the "to jam or not to jam" decision based on a developing tactical situation. This type of system would require an appropriate tactical understanding of Soviet Electronic Order of Battle and the tie between specific emitters and the target they represent.

AI could also provide a Deception Identification System that would aid in recognizing deception employment. Additionally, AI/robotics technology has potential in the area of simulation--deceiving the enemy by simulating the presence of troops, tanks, and weapons. A Portable Deception System could aid in this area.

2.2.1.3. NBC Capability

The Soviet Army is believed to have over 5000 tactical nuclear weapons deployed in Eastern Europe. Most of these are designed for high-yield low-altitude air bursts to provide maximum destruction from thermal and blast effects. Within several kilometers of even a low-yield tactical burst, nuclear effects, which might produce minimum personnel casualties, can render sophisticated electronic battlefield equipment useless. The electromagnetic pulse from tactical detonations can ruin transistor communications equipment and computer systems. Tanks with computers for fire control will experience failures. In addition to the obvious threat of destruction from nuclear blast or thermal effects, AI/robotics development must incorporate protection and hardening measures against these other electromagnetic effects.

The Soviet Union is known to possess extensive chemical warfare capabilities, including stocks of chemical munitions, defensive equipment and well trained troops. Soviet tanks, for example, are equipped with automatic chemical alarm systems. Their decontamination equipment is in operational inventory and they are well practiced in its use.

The Soviet Union might resort to chemical weapons to achieve a tactical objective. They might also want to preempt US/NATO use of an NBC option, in order to maintain momentum and continuous combat. The NATO use of NBC is bound to be more restrained due to the very nature of Western doctrine. The fact remains, however, that the Soviets are really the only major power to have fully implemented offensive chemical warfare doctrine.

A major area in which AI/robotics could aid in countering this threat is chemical detection. An NBC Sentry could provide advance warning of chemical attack. AI capabilities could aid in the detection of unforeseen chemicals and the rapid identification of the chemical agent involved.

2.2.1.4. PGM/IFF

A major advance that is expected in the next decade will be individual and unit precision-guided munitions (PGM) with IFF capabilities. This will advance the lethality capability of both the Red and Blue forces. The effectiveness of precision-guided munitions will become even more devastating as IFF discrimination increases. The types of munitions used and the demand for missions will probably increase as the pace of battle increases. While there has been considerable technical development in PGM, first generation PGM largely depend on clear air and high visibility. The next generation will incorporate some night and all-weather capability.

The potential of AI/robotics in this particular area resides, as an example, in the concept of countermeasures-activation and avoidance of incoming PGM. An Armor Hit-Avoidance System could provide a rapid means of activating countermeasures or hit-avoidance devices. This could eventually include the added capability of retaliatory/intercept strikes. AI also has the potential of advancing IFF technology as a module that could be adaptable to various military weapons systems.

2.2.1.5. Soviet AI/Robotics, Past History and Potential

The preceding section examined five aspects of threat doctrine and tactics that have implications for developing AI/robotics technology for Army applications. In addition, the potential threat posed by Soviet development of this very same AI/robotics technology must be considered. While this effort did not include any extensive analysis of Soviet/Warsaw Pact R&D efforts in AI/robotics, it is essential to note that USSR military AI/robotics capability will eventually constitute a threat to U.S. forces. We have not attempted to discuss the impact that U.S. AI/robotics technology transfer could have on Soviet R&D efforts in this field. We have considered some data points that strongly indicate that the Soviet Union is currently, and will in the future, pursue that which the U.S. is already doing--planning for the best utilization of AI/robotics for the military.

A discussion of Soviet activities in this area is contained in the classified supplement to this report. The overall indications are that the Soviet Union is pursuing an active research and development program in AI/robotics that could lead to military applications in combat and combat support.

2.2.2. Units

In this section, we examine unit operations that are essential to the effective performance of the combat/combat-support missions of the combined arms. The analysis presumes that the reader has an understanding of the fundamentals of combat/combat-support operations in the offense, defense and retrograde, and an understanding of the combat power of the U.S. division as the basic Army unit in the combined arms and services.

The U.S. Army is currently preparing for the first complete reorganization of its field forces since the inception of the ROAD* concept in the 1960's. The present division concept is in a state of transition, with new TOE's for armored and mechanized infantry divisions scheduled to commence as early as 1983. One of the many reasons for reorganization was the design objective of creating a heavy division to permit sustained unit operations, and to conduct a broader range of offensive and defensive operations critical to winning the land battle. Due to the reorganization transition, we have concentrated this analysis on problems inherent to a wide scope of operational missions.

The operation/function of a unit cannot be separated from the threat because our combat forces do not operate in a vacuum. The battlefield situation, predicated on the threat of opposing forces, requires highly mobile, firepower-intensive maneuver forces that are capable of independent operation within the scope of a highly synchronized effort. The state of the art of warfare and its dependency on technology demands such organization.

---

* ROAD--Reorganization Objective Army Division

The new organization of Armored Division 86 has been selected as an example to illustrate some of the changes that units are and will be undergoing. This new armored division organization is illustrated in Figure 1. NBC, CEWI, and signal units will be fairly standard in Division 86. The division organization contains three maneuver brigade headquarters, six battalions of armor, and four battalions of mechanized infantry. Both mechanized infantry and armored battalions are larger, with maintenance and administration consolidated in headquarters companies. One notable change is the air cavalry brigade, which consolidates all divisional aviation. Division 86 artillery is mainly responsible for close support of the maneuver battalions. There is an increased requirement for counterfire and the need to interdict follow-on threat echelons. One of the implications of these changes is that tactical planning and close coordination will be paramount to success. The pervasive rationale for restructuring is to utilize optimally all assets at our disposal and to incorporate efficiently technological additions that enhance tactical capabilities and offset numerical inferiority. The designations of the various divisional units as combat, combat support, and combat service support are shown in Figure 1.

Table 4 shows operational problems that will be faced by virtually all combat divisions. AI/robotics implications related to these problems, along with the AI/robotics concepts that could alleviate the problems, are also shown in the table.

2.2.2.1. Continuous Operations

The nature of continuous combat operations includes offensive and defensive combat at night and in reduced visibility. The ability of U.S. forces to conduct operations around the clock will be facilitated by the flexibility that has been built into the new organizations, but a continuous combat capability will have to become an integral part of all operations if we are to maintain sustained combat. When a unit is required to operate around the clock, human endurance is a central issue

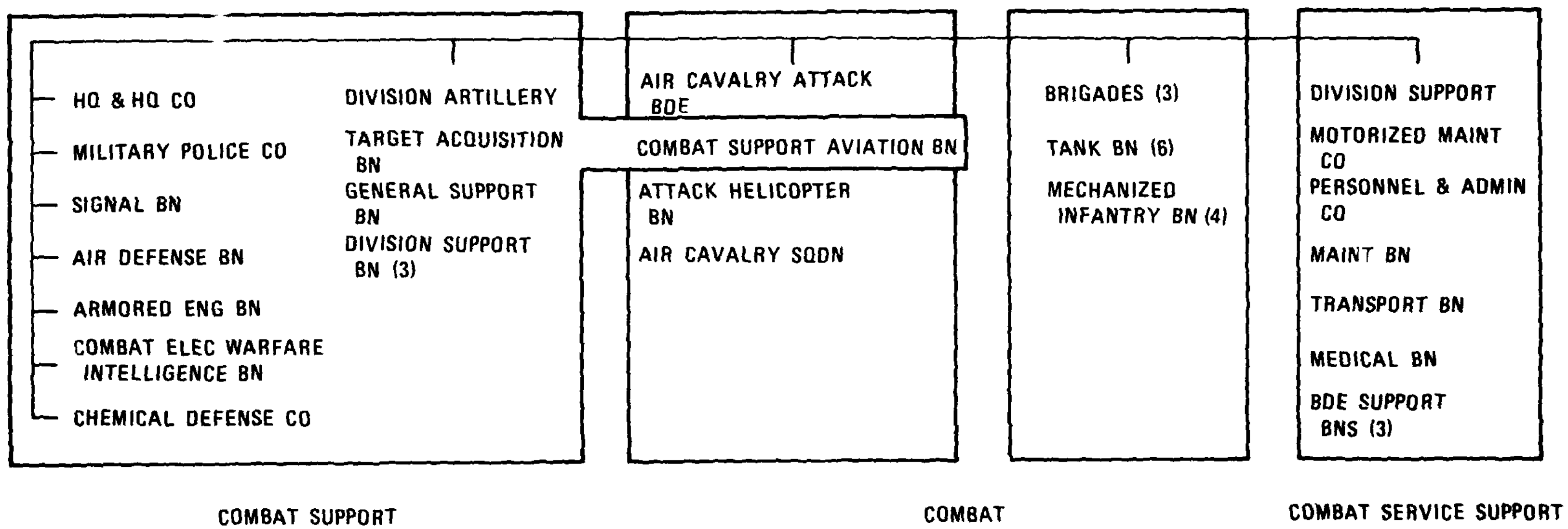


FIGURE 1 ARMORED DIVISION UNITS (DIVISION 86)

Table 4

UNIT OPERATIONAL IMPLICATIONS

Unit Problems Offense-Defense-Retrograde	Problems and Implications for AI/Robotics	Application Concepts
Continuous operations/ reduced visibility	Sustained firepower Vision enhancement	Heavy Fighting Sentry Remote Scene Analyzer Soldier's Auxiliary Eye
Coordination of weapons with maneuver	Rapid accurate target suppression Observed Fire Mobility	Fire Allocation and Control System Ground Observer/ Designator Artillery Movement Assessment System Mine Clearer
C3 responsiveness, reliability, integrity	Rapid tactical planning Reliable information exchange	Brigade Mission Planning Aid Communications Network Manager
EW operations and vulnerability	Responsive countermeasures Flexible tactics	EW Sentry Adaptive EW Control System
Tactical nuclear/ chemical, operations	Contamination avoidance Speed	NBC Reconnaissance Robot Vehicle Decontaminator
Unit assimilation of high technology	Human-machine interface	Voice Helicopter Control System Division Commander's Voice Data-Base Access System

in sustaining combat and combat-support operations. AI/robotics technology has the potential of increasing a unit's combat power by augmenting its fighting capability to ensure sustained operations. The concept of a Heavy Fighting Sentry would augment an infantry unit's fighting capacity by acting as an integral forward defense element against enemy troops, for example.

Reduced visibility (regardless of the time of day) presents an area in which AI/robotics can provide assistance, for example, with vision enhancement devices. A great deal of research still has to be accomplished in the field of vision applications; however, the concepts of the Remote Scene Analyzer and a Soldiers Auxiliary Eye are conceivable long-range systems.

2.2.2.2. Coordination of Weapons with Maneuver

Maneuver and continuous operations are essential aspects of combat power that are attained by deploying mobile, responsive, combined-arms forces against the enemy. As units concentrate, they become more vulnerable to enemy fire. Maneuver must coincide with suppressive strikes against enemy weapons, with enough strength and duration to degrade the effectiveness of enemy weapons in the area of operations. Suppression requires combined arms teamwork of the highest order. Each time a unit breaks cover and moves out into the open, success of the operation can rest on the rapid and accurate use of suppressive fires. Establishment of priorities for suppression becomes crucial, so that supporting field artillery will know where to allocate resources and how to time the strikes or appropriate countermeasures. The ability to sustain weapon systems employment is essential for attack momentum, and the deeper the attack, the more difficult this requirement becomes.

AI/robotics can provide assistance in the aforementioned areas of fire and maneuver. First of all, AI could assist in rapid, accurate, target suppression by the use of a Fire Allocation and Control System. The human forward observer could be replaced in many cases by a Ground Observer/Designator. Effective employment of suppressive fires could be aided by an Artillery Movement Assessment System. Maneuver momentum and mobility can be enhanced by a Countermine Vehicle that saves manpower and rapidly clears obstacles so an advance is not delayed.

2.2.2.3. Command, Control and Communications

The conduct of any highly active mobile operation demands continuous C^3. In fact, we can say that all combat/combat-support operations mandate reliable C^3. When a commander has to operate far forward, the problem is compounded. In order to maintain unit agility, C^3 must be dependable. If the technological advances that AI/robotics affords can give a commander the timely capacity and opportunity to plan for and implement a decisive offensive maneuver, this could be the key to a tactical victory. The newer Army doctrine of the deep attack implies increasing emphasis on close coordination and timely response between ground and air, on the ability to plan and exploit an attack, and on the ability to select targets. The responsiveness, reliability, and integrity of the C^3 network has to be maintained in order to coordinate tactical planning with mission implementation. Just how our C^3 architecture will influence the effectiveness of our combat systems remains a critical question. C^3 is so vital to the operation and combined mutual support of units that it has rapidly become the means by which tactical plans are transformed into combat power. In short, C^3 is so much an integral part of tactics that it is virtually a weapon, with all the resultant implications.

The ability of a commander to plan rapidly can be facilitated by the use of an AI concept termed the Brigade Mission Planning Aid. This concept would incorporate those essential elements of tactical plans that permit the commander to interactively analyze his combat/combat-support and engagement exploitation options. The Communications Network Manager concept has the potential of ensuring that the responsiveness and integrity of a network are maintained and that mission data are disseminated accurately and in a timely fashion.

2.2.2.4. EW Operations and Vulnerability

Coordinated disruption of electronic C^3 elements, surveillance, targeting and weapons guidance systems can effectively diminish offensive capability. Such disruption can reduce the number of weapons

that arrive at their targets, confuse armor/troop movements, and abort command-control efforts. Defensive posture is weakened as the ability to correctly perceive the locations, movements, and intentions of enemy forces is reduced through the use of jamming, deception and physical destruction of sensors. Thus, the goal of EW in the defense is to deny the enemy the ability to properly coordinate and direct his offensive forces. Similarly, the main objective of EW in offensive actions is to destroy or degrade the enemy's C^3.

In order to reduce our vulnerability and increase our offensive capability, it is evident that an effective countermeasures approach is dependent in large measure on the timely interaction between sensor systems that can intercept, locate, and identify the enemy's EW efforts, and friendly jammers and deception devices that can counter them. The AI/robotics concept of the EW Sentry could permit timely and responsive countermeasures operations to be initiated--along with an Adaptive EW Control System for flexibility.

In general, AI could be applied to EW systems in the areas of adaptive properties, decision-making capability, processing "exotic" signals and enhancing the ability to prioritize EW threats.

The CEWI battalion as part of division assets contains many of the SIGINT collectors and EW jammers necessary to correlate the division commander's ability to target and disrupt both immediate assault and follow-up echelons. Selected aspects of AI can aid in the selection of appropriate countermeasures techniques by assisting in the management of available resources, including the analysis of real-time sensor data for emitter identification, emitter location, threat identification, prioritization, technique selection, direction, frequency, power and tactical coordination.

2.2.2.5. Tactical Nuclear and Chemical Operations

The Army's capability to conduct tactical nuclear and chemical operations and to operate in a contaminated environment will be enhanced by the addition of the NBC company to the new division organization.

Also, decontamination assets have been added to each battalion in the division.

Enemy units could utilize persistent chemicals in a tactical role immediately behind friendly lines to contaminate communications, river crossing sites, transportation, etc., necessary for reinforcement and supply. It is also possible that the Soviet/Warsaw Pact may employ non-persistent agents against friendly unit positions close to Soviet lines and against airborne or airmobile landing zones just prior to landing their assault troops. The enemy may employ chemical agents against such targets as headquarters, assembly areas, artillery positions, and NBC units. They may also be expected to employ chemicals in a flank guard role and along the projected flight path of their own airborne insertions.

Without large-scale, rapid, practiced, decontamination capability, the U.S. forces ability to conduct operations of any kind will be seriously degraded. It is not only a matter of decontamination. The NBC problem also entails early warning, proper identification of the contaminant being used, and handling of contaminated equipment, weapons, and casualties. As in other operations, AI/robotics has the potential to increase our survivability and capacity to maintain an operational capability in a contaminated environment.

Avoidance of contaminated areas requires rapid reconnaissance to define the nature and extent of contaminated areas. The NBC Reconnaissance Robot could greatly aid this process.

Another major problem faced by mechanized forces is rapid and effective decontamination of equipment. The Vehicle Decontaminator could provide a rapid method of accomplishing this action, and reduce the hazards to troops involved in present techniques.

2.2.2.6. Unit Assimilation of High Technology

The increasing introduction of sophisticated equipment, including electronic computerized items into units, implies that successful

operations will depend heavily on the assimilation of high technology items as useful battlefield tools. Improved combat effectiveness will not only rely on the success of the division reorganizations, but also on the ease with which new technology and systems are integrated into a unit. In short, soldiers must be able to use the equipment, and understand how it fits into an operation, if technology is going to give us an advantage. We have already discussed the increasing electronic sophistication on the battlefield. AI can act as an interface between the human and complex machines by simplifying the means by which control is exercised. The Voice Helicopter Control System and the Division Commander's Quick Database-Access System are two example concepts in this area.

2.2.3. Equipment

The analysis of Army combat and combat-support equipment considered items which are currently in inventory and projected through the year 2000. The purpose of the analysis was to identify current and projected problem areas that might be resolved or alleviated by the application of AI/robotic concepts. Information gathering to support this analytic process included discussions with many Army agencies and review of major studies as described in Section 2.1. The review included such major material-program-acquisition-system documentation as Mission Element Needs Statements (MENS), Required Operational Capabilities (ROC), Letters of Instruction (LOI), Letters of Agreement (LOA), Program Objective Memoranda (POM), and approved budgets, and long-range R&D plans.

2.2.3.1. Equipment Categories

Since all equipment items could not be considered in detail, it was necessary to develop a suitable means of categorizing equipment. An extensive examination of Army methods for categorizing equipment was conducted. The techniques considered ranged from the Federal Supply Class (FSC) of the National Stock Number (NSN) to the commodity-related

organization structure of the DARCOM commands. It was decided that a slightly modified version of the Army Concepts Analysis Agency's (CAA) Wartime Active Replacement Factors (WARF) vulnerability categories would serve as a convenient aid to this analysis. The categories selected for the purpose of this study are depicted in Table 5. Combat service support was included to assure completeness, although consideration of applications in this area was not within the scope of the effort.

Table 5

SRI EQUIPMENT CATEGORIZATION

Combat	Combat Support	Combat Service Support
Aircraft	Light vehicles	Towed equipment
Light armor	Light boats and equipment	SP equipment
Medium/heavy armor	Vehicle bridges and ferries	Ammunition/POL transport
Tube artillery	Armored POL/ammunition transport	Machines
Missiles	Communication-electronic devices	Shop sets
Infantry crew-served weapons	Miscellaneous small equipment	Light POL storage
Small arms		Water tanks
Instrument, optics and illumination		

Within the equipment categories under Combat in Table 5 'Aircraft' includes fixed wing, rotary wing, remotely-piloted vehicles, and autonomous air platforms. 'Light armor' includes personnel carriers, self-propelled artillery, and resupply/repair/recovery vehicles, while 'medium/heavy armor' includes armored combat engineer vehicles and tanks, etc. 'Tube artillery' includes both towed and self-propelled

mortars, guns, howitzers, and rockets. Similarly, ´missiles´ include those surface-to-surface missiles used in a tactical fire-support role. The ´small arms´ category includes rifles, pistols, and other hand-held weapons and ordnance, while ´infantry crew-served weapons´ includes ground- and vehicle-mounted weapons served and/or operated by more than one person. The final category, ´instruments, optics, and illumination´ includes such items as night-vision devices, lasers, and other sensors used for surveillance, target acquisition and fire control.

Within the Combat-Support Equipment categories in Table 5, ´light vehicles´ includes small trucks up to 3/4 ton. ´Light boats and equipment´ includes boats used in wet-obstacle crossing for transporting personnel and bridging, etc. ´Vehicle bridging and ferries,´ by comparison, includes heavier bridging components whether erected, floatable, or vehicle launched. ´Armored petroleum, oils, and lubricants and ammunition transporters´ includes armored fuel, ammunition, and cargo-tracked vehicles. Finally, ´communications-electronics devices includes radios, switchboards, and wire devices, etc.

Under the Combat-Service Support column in Table 5 ´towed equipment´ includes nonweapons items such as cargo trailers, generators, and towed wheeled vehicles. ´Self-propelled equipment´ includes those prime mover trucks and tractors for the towed equipment mentioned above. (Many of these same vehicles are also applicable in the Combat-Support column since they are organic to the TO&E of combat-support units as well as combat-service-support units, where they act as prime movers for towed artillery, etc.) ´Ammunition/POL transporters´ are those wheeled vehicles such as trucks, trailers, tractors that are nonarmored cargo carriers or refuelers. ´Machines´ include such items as small air compressors, generators, reeling machines, etc., that do not require mounting on another platform because of their size and weight. ´Shop sets,´ by comparison, include both trailer and van-mounted tools and testing equipment that are generally of sufficient weight and bulk to be mounted and used on a movable platform. ´Light POL storage equipment´

includes such items as bulk fuel dispensing and storage equipment, while 'water tanks' includes large, collapsible, fabric tanks of various sizes.

In examining the various older in-use, issued replacement, and planned equipments that fell into the above categories, it became evident that, as old items were replaced with new ones, some of the same problems seemed to be perpetuated, while others disappeared. Sometimes, depending on the complexity of the replacement equipment, totally new problems seemed to be introduced. Many of these "surviving" problems could affect mission accomplishment in combat. In a generic sense, these problems may result from such things as inadequate design, the limits of technology, greater than expected maintenance, lack of trained operators/maintainers, and/or the increasing lethality of the combat environment. While not all of these contributing factors can be controlled, some can and are being addressed by the Army in product improvement programs, next generation designs, and enhanced training.

It is also conceivable that, where the human factor perpetually plays a large role in equipment and mission failure, a conscious effort to progressively design the human out of the equipment may result in increased performance and reliability over time. Similarly, an item of equipment is often required because the human is consistently in a hazardous, life-threatening operating environment. If it is possible to incorporate human qualities in such equipment by design, thereby effectively removing or reducing the necessity for constant human presence without degrading operational capability, lives and manning spaces might be saved.

With these and other goals in mind, the analysis focused on development of conceptual solutions to the equipment-related problems identified. In this process, attempts were made to develop generic conceptual solutions as well as specific AI/robotics concepts. Where possible, modular or "building-block" robotic concepts were developed.

2.2.3.2. Combat-Equipment Implications

Problem areas in combat equipment, as they relate to AI/robotics, are shown in Table 6. The table also shows selected application concepts that could alleviate the problems.

Table 6

COMBAT EQUIPMENT IMPLICATIONS

Category	Problems and Implications for AI/Robotics	Application Concepts
Aircraft	Rapid re-arming	Helicopter Missile/ Rocket Reloader
	System control complexity	Copilot
	Pilot/system recovery	Safe Return Controller
Light armor, medium and heavy armor	Rapid re-arming/servicing	Armored Resupply and Servicing Vehicle
		Tank Ammunition Handler
	Crew size	Tank Gun Loader
Tube artillery	Ammunition handling	Artillery Loader
		Ammunition Handler
	Forward observation	Ground Observer/ Designator
Missiles	Critical launch timing	Missile Launch Trouble Shooter
	Rapid nuclear fire planning	Nuclear Fire Planner
	Rapid PNL handling	Nuclear Munitions Outloader
Small arms	Soldier vulnerability	Infantry Robotic Grenade
		Light Fighting Sentry
Infantry crew-served weapons	Soldier vulnerability	Homing Tank Killer
Instrument/ optics/ illumination	Visual obscuration	Scene Interpreter/ Clarifier

Within the category Aircraft, three concepts were identified that address themselves to the inherent complexity of helicopter operations. The Helicopter Missile/Rocket Reloader would be a robotic system for servicing attack helicopters at forward rearming points. It would offer the advantages of speed and armor protection for ground support personnel as opposed to present-day exposed, human-labor-intensive systems. (Similar systems could be conceived for refueling.) The system would increase aircraft mission availability. Copilot would be an artificial intelligence system that would perform the functions of the copilot in attack helicopters. This concept would save spaces, training time, and the weight of a two-versus-one-man aircraft. It is expected that improvements in both aircraft and mission performance would result. Safe Return Controller would be an on-board artificial intelligence system that, upon sensing pilot dysfunction, would assume flight control, including returning the aircraft to a safe landing.

Among the Armor category concepts, the Armored Resupply/Service Vehicle incorporates several robotic applications that would allow rearming, refueling, and minor repair in conventional as well as NBC battlefield environments. The concept could speed complete servicing and rearming of tanks and, thus, increase their availability for combat. The Tank Ammunition Handler would be a system to speed the process of rearming tanks in forward areas. It would perform all the functions of moving the round from its transporter directly into the storage compartment in the tank. It would be a less complex, shorter-range concept than the Armored Resupply Service Vehicle, but it could also contribute to reducing rearming time. The Tank Gun Loader would be an automatic loader that would select and move the rounds from the storage compartment into the gun. It could allow elimination of the loader from the tank crew.

Within the category tube artillery, problems exist in ammunition handling that are somewhat similar to those in tanks. The Artillery Loader would be a robotic device that would select, lift, remove the lifting plug, fuze the projectile and present it into the breech of the

gun/howitzer. Such a system would save several manpower spaces per tube artillery crew, and would be capable of continuous operation and rapid displacement as necessary. The Ammunition Handler, by comparison, is a robotic device that is used to load ammunition carriers at the forward-area ammunition-resupply points. The Ground Observer/Designator concept would provide for the robotic functions of a forward observer while incorporating the capability to illuminate a target with a laser for engagement by indirect or direct fire weapons. The benefits of such a system would include savings in spaces, and substitution for soldiers in a hazardous task.

Within the ´missile´ category, the Missile Launch Trouble Shooter would address itself to the problem of critical launch timing. This artificial-intelligence-based system would provide on-site, interactive diagnosis and corrective maintenance information for surface-to-surface missile launching systems beyond the capability of automatic test equipment to handle unusual problems. It, thus, would act as an advisor/prompter/consultant to the crew. Such a system could increase system mission performance, by allowing the crew to recover from unusual failure or fault situations during the launch sequence. The Nuclear Fire Planner, an artificial-intelligence-based system, would perform rapid and accurate assessments of related tactical data in preparation for fire missions. It would be integrated with other target information, acquisition and fire-control systems, thereby performing many of the detailed and time-consuming planning functions and data-processing tasks otherwise done by humans. The Nuclear Munitions Outloader robotic concept could speed the outload of PNL from storage sites when such action was ordered.

Consideration of the ´small arms´ category leads primarily to concepts that address problems of soldier vulnerability by man-extension techniques. The Infantry Robotic Grenade would be a self-propelled, programmable ordnance item capable of self-navigation to a target, which might include personnel positions, obstacles or heavy equipment. It would have designed features that would preclude its use by the enemy or

reverse of direction once underway. Such a device would serve to minimize the exposure of soldiers in close offensive combat situations, particularly against fortified positions. The Light Fighting Sentry, likewise a robotic concept, would be both man-extending and force-multiplying and modular in design. This robot would be capable of performing sentry functions including delivering small arms fire on enemy targets. Sentries plus their human counterparts would be task-organized for particular offensive or defensive missions. (Other derivatives of Sentry could incorporate heavier direct fire weapons, all weather, surveillance, and EW capabilities. These concepts could increase the effectiveness of units, possibly reduce the spaces necessary to achieve this effectiveness, and reduce the vulnerability of the individual soldier, while providing for continuous combat operations.)

Within the category of 'infantry crew-served weapons,' the Homing Tank Killer would be an expendable, smart, robot that could be employed by individual soldiers. The device might well be like the Infantry Robotic Grenade, but with longer range and capable of seeking armored targets through its self-contained homing sensor capabilities. The system could reduce exposure of crew members to counterfire and reduce manning spaces for existing anti-tank systems. The Heavy Fighting Sentry, a sentry derivative, would be capable of direct fire against ground vehicle targets. Either light or armored vehicle-mounted, it would be used in conjunction with other sentries and/or man-machine systems to acquire targets and distribute fire. Again, this is an example of a modular robotic concept that would serve as a force-multiplier and reduce man-machine system vulnerability.

The category of 'instruments, optics and illuminations' suggests concepts that have broad application among the entire set of equipment categories since such systems address themselves to "seeing," whether it be for observation by a single soldier or target acquisition by a weapon system. Further, incorporating such human qualities as the ability to discern discretely among objects in a scene would increase the

intelligence and autonomy of these systems. It then follows that the requirement for a continuous human interface could be reduced to an exception basis. Such a system, the Scene Interpreter/Clarifier, would address the perennial problem of seeing, discerning and interpreting battlefield information, day and night, and in all weather conditions. The purpose of this system would be to aid the soldier during periods of both normal and impaired visibility in the identification of battlefield images or objects. It would be a module that could be attached to, or used in conjunction with, such inventory items as imaging devices. The Scene Interpreter/Clarifier would be able to discern an object or image when it was partially obscured or camouflaged. The soldier would be able to isolate a field in which he wanted to have an image identified, and the module would alert the soldier to potential hazards/impending lethality if present in that field. (An alternate version could discern among the images identified based on its knowledge base and communicate to other systems [weapon, intelligence] what it "sees." Operating in an autonomous mode, it might serve as a "super" target acquisition device in a target-rich environment for other robotic weapons systems.) This concept would reduce the vulnerability of the individual soldier and mitigate the problems of battlefield obscuration.

2.2.3.3. Combat-Support Equipment Implications

Problem areas in combat-support equipment, as they relate to AI/robotics are shown in Table 7. The table also shows selected application concepts that could alleviate the problems.

Table 7

COMBAT-SUPPORT EQUIPMENT IMPLICATIONS

Category	Problems and Implications for AI/Robotics	Concept Examples
Light vehicles	Soldier vulnerability	Combat Porter
Light boats and equipment	Soldier vulnerability	Semi-Autonomous Assault Raft
	Current/bank effects	River Reconnaissance System
Vehicle bridges and ferries	Soldier workload	Soldier's Slave
Armored POL/ ammunition transport	Rapid servicing	Refueler
		Armor Resupply/Servicing Vehicle
Communications-electronics devices	Antenna erection	CP Antennae-Remoting System
	Relay requirements	Remote Communications Relay
		Adaptive Airborne Communications Relay
	Network monitoring/ management	Signal Array Planner
		Communications Network Manager
	EW vulnerability	Adaptive EW Control System

Within the first category, 'light vehicles,' the robotic concept Combat Porter is directed at reducing soldier vulnerability and saving human labor. This concept, a human-directed robot, would perform such basic tasks as lifting heavy objects, transporting them to a designated place, unloading them, and returning to the point of origin.

In the 'light boats and equipment' category, the Semi-Autonomous Assault Raft would afford both passenger protection and semi-autonomous operation over wet gap crossings. It would be used in conjunction with the River Reconnaissance System, which is also a robotic device. The River Reconnaissance System would first reconnoiter the water obstacle and provide information about the bottom, water conditions, bank slopes, egress soil condition and presence of mines. These concepts would

contribute to the reduction of hazards to personnel associated with these types of operations.

The category of ´vehicle bridges and ferries,´ suggests concepts such as the robotic Soldier´s Slave. The Soldier´s Slave would assist in the heavy lifting and moving such as those construction tasks associated with bridge erection, as well as preparation of the routes of egress and ingress to the crossing point(s). This concept specifically addresses the problem of reducing the soldier´s workload and possibly saving spaces.

Within the category of ´armored POL and ammunition transport,´ the Refueler is a robotic device that would be used in conjunction with conventional bulk POL delivery systems. It would locate fuel filling points on small and light vehicles and dispense fuel remotely, thus minimizing the exposure of personnel to the hazards of the operating environment and speeding operations. The Armor Resupply/Servicing Vehicle discussed in Section 2.2.3.2 also is suggested by consideration of this category of equipment.

The ´communications-electronics devices´ category presents a mix of problems and concepts. The CP Antenna-Remoting System would transport and erect radio antennas, thereby saving labor and diverting the inherent electronic signatures away from the command post. The Remote Communications Relay concept would be a radio relay device capable of autonomous land navigation to the point of employment, where it would automatically, or on command, erect its antenna and function as a relay station (an air- delivered version of this concept is also possible). The Adaptive Airborne Communications Relay would be an airborne system to perform radio relay functions. It would be mounted in a remotely-piloted vehicle or an unmanned autonomous aircraft platform capable of recognizing and acting on propagation medium changes, electronic countermeasures and line-of-sight restrictions. The Network Manager, a communications system artificial intelligence concept, would perform network management functions such as routing, connectivity assessment, user authentication and overall system control. It would save labor and

provide for continuous, error-free operation as opposed to current methods. The Signal Array Planner, another AI-based system, would plan the optimum connectivity of the network, while the Adaptive EW Control System would involve the use of sensors to intercept, locate and identify the enemy in support of EW plans and operations. Once interception was accomplished, it would assist in making the decision to continue the intercept, jam, deceive, destroy, or reassess the situation. These systems, integrated and working together, would provide for a significant increase in command, control, and communications effectiveness while contributing to the mitigation of vulnerability.

2.2.4. Functions

An alternative viewpoint for identifying useful AI/robotics applications is the examination of the functions associated with the combat and combat-support system of the Army. The Army has defined eight broad functional areas, which provide a useful basis for the examination. These provide the current partitioning of Army activities for addressing Army problems and needs via Mission Area Analyses. In this section, these functions and their subfunctions are considered and pertinent AI/robotics concepts derived.

2.2.4.1. Functional Areas

The eight broad functional areas defined by the Army are as follows:

* Close combat
* Fire support
* Air defense
* Command and control
* Communications
* Intelligence and electronic warfare
* Combat support, engineering, and mine warfare
* Combat service support

The combat service support function was not considered in this analysis. The other functions can be aggregated into combat and combat-support categories as follows:

* <u>Combat Functions</u>

(1) Close combat

(2) Fire support

(3) Air defense

* <u>Combat -Support Functions</u>

(1) Combat support, engineering, and mine warfare

(2) Command and control

(3) Communications

(4) Intelligence and electronic warfare

The combat and combat support functions have been further expanded to highlight some of the associated subfunctions. These are listed in Table 8.

Table 8

COMBAT AND COMBAT SUPPORT FUNCTIONS AND SUBFUNCTIONS

Category	Function	Subfunction
Combat	Close combat	Direct fire (individual) Maneuver Defend
	Fire support	Indirect fire Direct fire (crew)
	Air defense	Antiaircraft fire
Combat support	Combat support, engineering, and mine warfare	Construction, bridges, barriers Obstacle breaching/avoiding
	Command and control	Data processing Situation assessment Planning Coordination
	Communications	Transmit and receive COMSEC Voice and data
	Intelligence and EW	Enemy information Reconnaissance EW

The identification of subfunctions provides a means to assist in the orderly identification of associated problems that may have AI/robotics implications.

In the following sections, an official definition of each functional area is followed by a brief discussion introducing the selected concept examples. A more complete description of the selected concepts can be found in Appendix A.

The identified problems that flow from the combat and combat-support functions and subfunctions shown in Table 9 through 17 tend to suggest long-range research and development issues. They are helpful in focusing on AI/robotics implications. The problems, which will be ultimately identified in the Army's Mission Area Analyses (MAA) of these functions, would certainly be important in identifying potential

applications, but further analysis may indicate that they may have a rather short-term focus. A leap in AI/robotics technology may obviate the necessity for dealing with these shorter-term issues. In any case, since most of the MAAs were not available, they have not been used as a basis for this functional analysis.

2.2.4.2. Close Combat

Close combat addresses those efforts directly related to the direction and generation of combat power by light, medium, and heavy forces for the purpose of destroying enemy forces in the direct fire battle. Close combat includes the employment of support weapons organic to maneuver forces as well as close air support, attack helicopters, and directed energy weapons. Included are maneuver, target acquisition, battle control, target processing, target attack, and target-attack assessment. Implied is the requirement to secure and hold terrain when necessary.

Close combat implies direct "eyeball to eyeball" contact with the enemy. As indicated in Table 9, close combat with the enemy could come about in a number of ways including direct fire, maneuver, and defense. The principal threat to the soldier in the conduct of close combat is being engaged by the enemy. This results from being observed and then being fired upon by a direct-fire weapon.

The implications for AI/robotics derive from the direct-fire situation and the solution lies in countering the enemy's observation and fire. This is accomplished by maneuvering while at the same time maintaining accurate orientation (position location), by providing physical and NBC protection for the soldier, and finally, by building barriers as situations permit to keep the enemy at a distance, or slow his advance.

Some application concepts that substitute a robotics device for a soldier in a direct-fire situation are indicated. In each case, the robotic device assumes the position and function of a soldier engaged in close combat. Because of the robot's design characteristics, it not

only substitutes for human vulnerability, it also is less vulnerable to counteraction because of its size and sustainability.

Table 9

CLOSE COMBAT IMPLICATIONS

Subfunction	Problems and Implications for AI/Robotics	Application Concepts
Direct fire	Counterfire or observation	Light Fighting Sentry Infantry Robotic Grenade
Maneuver	Position location	Soldier's Auxiliary Eye
Defend	Physical protection Obscuration Barriers	TEARS/DEMONS Smoke Layer Mine Emplacer Mine Clearer

2.2.4.3. Fire Support

Fire support addresses those efforts directly related to the direction and generation of direct and indirect fires, to include electronic warfare means and includes those related to close combat, for the purpose of suppressing, destroying, degrading, or disrupting enemy locations, systems, or formations. This includes the attack of enemy forces extending the full depth of the enemy formations. The fire-support process includes target value analysis and fire distribution for the selection and determination of critical targets and the selection and timing of the most effective attack mode. Fire support mostly concerns indirect fire, but also implies the crew-served direct-fire weapon as opposed to the individual direct-fire weapon discussed under close combat.

The problems and implications for AI/robotics that are shown in Table 10 revolve around the critical functions connected with firing weapons and the expected enemy countermeasures. In order to effectively fire friendly artillery, an observer must locate and identify a target. This requires target observation and an accurate knowledge of where the

target, friendly artillery, and observation position are located. The potential target must be identified as friend or foe. Consideration must also be given to denying the enemy knowledge about our own forces to preclude him from effective use of his own fire support. His knowledge of our firing positions will cause counterfire. In addition, he can target our communications in order to destroy a friendly command post. And, finally, even without pinpoint accuracy, he can target a general suspected area with NBC weapons.

Table 10

FIRE SUPPORT IMPLICATIONS

Subfunctions	Problems and Implications for AI/Robotics	Application Concepts
Indirect fire	Target observation	Ground Observer/Designator Aerial Observer/Designator
	Target identification	IFF Module
	Position location	Super Sextant
	NBC protection	NBC Sentry
	Communications	Remote Communications Relay
Direct fire	Crew vulnerability	Heavy Fighting Sentry

2.2.4.4. Air Defense

Air defense encompasses those efforts directly related to destroying, disrupting, or degrading the effectiveness of enemy air-breathing systems, tactical missile systems, and satellites used for reconnaissance or attack of friendly facilities, personnel, and systems. Included are aircraft, missiles, munitions, and target acquisition means integral to the air defense system.

Air defense implications and concepts are shown in Table 11. The air defense function concerns itself with the rapid identification and destruction of enemy aircraft. A major problem for AI/robotics is in the identification friend or foe (IFF) of aircraft. If friendly, they must not be engaged, and if foe, they must be destroyed before they

engage friendly ground targets. This IFF problem pervades many potential AI/robotic weapon systems. An IFF Module addressing this problem would be an AI system that can rapidly recognize discrete aircraft signatures, thereby permitting engagement and destruction of enemy aircraft, while at the same time precluding engagement of friendly aircraft.

Table 11

AIR DEFENSE IMPLICATIONS

Subfunctions	Problems and Implications for AI/Robotics	Application Concepts
Antiaircraft fire	IFF	IFF Module
	Engagement	Close Air-Defense Sentry

2.2.4.5. Command and Control

This function encompasses the capabilities required by a commander to review and analyze information, assess the situation, and to direct, manage, and control forces during operations in the accomplishment of his mission. Included is the iterative process of monitoring the enemy and friendly situation, planning, and replanning, estimating, deciding, providing for operations security and selecting and directing the correct option based on the overall scheme. Information systems and those systems required for controlling and releasing nuclear and chemical weapons are integral to this function.

Command and control implications and concepts are shown in Table 12. Command and control conducted by Army leaders relies on accurate and timely information on many factors that affect the outcome of the battle. Although great strides have been made in providing information from which commanders must make decisions, little has been done to uncomplicate the process or to crystallize that information which is vital to mission success. It is in solution of these problems that AI has tremendous potential. Many useful applications are within

the potential solution realm of AI. Examples are: the ability to cull, store, recall details on the enemy weather and terrain; the ability to route messages, select frequencies and automatically adjust to the effects of enemy actions; the ability to do detailed complex NBC planning; and the ability to keep track of a constantly changing situation.

The capability of a commander to use his voice to access data bases in order to obtain updated information even in operations concept formulation would be a great benefit.

Table 12

COMMAND AND CONTROL IMPLICATIONS

Subfunctions	Problems and Implications for AI/Robotics	Application Concepts
Receive, process, analyze	Too much information, not culled	Multi-Sensor Data Assimilator
Assess situations	Speed, currency	Mission Execution Monitor Brigade Situation Analyzer
Formulate plans, issue orders	Rapid changing situations	River Crossing Planner Nuclear Fire Planner Division Commander's Quick Data Access System
Coordinate forces, fires, support	Rapid execution in changing situations	Brigade Mission Planner

2.2.4.6. Communications

Communications include the capability to transmit and receive timely information flow among different echelons of the force and its sustaining base. Included is the capability to communicate from widely dispersed positions in an enemy-induced electro-magnetic pulse, nuclear, biological, chemical, or electronic warfare environment.

Communications implications and concepts are shown in Table 13. Two aspects of "communications" appear to be particularly attractive

candidates for AI/robotics technology. The ability to remotely reposition communications system equipment (antennas, transmitters, generators, etc.) or to remotely reset or replace damaged equipment would permit the operation in a hostile environment. In addition, by remote movement of signature emitting communications elements, the location of important command and control nodes can be disguised.

Table 13

COMMUNICATIONS IMPLICATIONS

Subfunctions	Problems and Implications for AI/Robotics	Application Concepts
Transmit and receive	Rapid antenna erection Transmission over hostile territory	CP Antenna-Remoting System Remote Communications Relay
COMSEC	Intercept capabilities	Adaptive Airborne Communications Relay
Voice and data	Network optimization	Communication Network Manager

2.2.4.7. Intelligence and Electronic Warfare

Intelligence and EW addresses the capability to determine type, characteristics, disposition, movement, and intention of enemy units as a support to battlefield management and the acquisition of targets. It includes the exploitation of reconnaissance information gained by close combat forces in addition to the employment of ground and air reconnaissance systems to collect information. Additionally, it includes the means to analyze, correlate, and integrate information to form usable intelligence and to disseminate that intelligence. The intelligence system is netted with the various firepower target acquisition systems. Electronic warfare includes the capability to detect, identify, locate, report, disrupt, destroy, deceive, and exploit enemy electromagnetic systems and includes those efforts taken to protect friendly electromagnetic systems.

Intelligence and EW implications and concepts are shown in Table 14. Intelligence must be timely and accurate in order to be of maximum benefit to a commander. Getting to crucial information and drawing accurate conclusions is within the range of AI technology.

Table 14

INTELLIGENCE AND EW IMPLICATIONS

Subfunctions	Problems and Implications for AI/Robotics	Application Concepts
Enemy information	Fusion	Tactical Threat Projection System
	Rapid collection	Interrogation Support System
Reconnaissance	Accuracy, change, speed hazards	NBC Reconnaissance Robot Tactical Reconnaissance Robot
EW	Headquarters signatures Responsive countermeasures	CP Antenna-Remoting System EW Sentry

2.2.4.8. Combat Support, Engineering, and Mine Warfare

This function addresses those efforts related to combat engineering operations and mine/countermine warfare. It encompasses the tasks of mobility, countermobility, and survivability. It includes position fortification, NBC hardening, and the emplacement/breaching of barriers and obstacles. Included is planning for the employment of families of mines, base/road construction and maintenance, bridging and power generation.

Implications and concepts are shown in Table 15. This function has several aspects that lend themselves to being addressed by AI/robotics technology. In general, these engineering type activities involve heavy equipment, operations in hostile environment, intensive labor, adverse

terrain, and danger from enemy action. The application concepts deal with one or more of these aspects. The fact that the River Reconnaissance System, for instance, could perform certain functions in the immediate combat area, would not preclude its optimal operation in rear area situations. In both instances, it would replace a time-consuming, dangerous human endeavor.

Table 15

COMBAT SUPPORT, ENGINEERING, MINE WARFARE IMPLICATIONS

Subfunctions	Problems and Implications for AI/Robotics	Application Concepts
Construction/bridge building/barriers	Exposure to fire	River Reconnaissance System
	Danger of detonation	Barrier Emplacement Aid
	Speed of emplacement	Mine Emplacer
Obstacle breaching/ avoiding	Speed and secrecy, terrain variables, marking	Engineer Reconnaissance Robot Mine Clearer

2.2.5. Environment

Consideration of the implication of the battlefield environment for AI/robotics involves two distinct aspects. As in the other analyses, environmental factors in themselves can suggest potentially useful AI/robotic concepts. In addition, it must be recognized that AI/robotics is an emerging technology, which, to this date, has not included development of systems for operation in the battlefield environment. That environment implies several needs that must be accounted for in any development program that is intended to produce actual fielded systems. Both of these aspects are discussed in this section.

2.2.5.1. Environmental Implications and Application Concepts

Five major environmental factors were considered in this analysis. They are:

* Terrain
* Climate
* Visibility
* Obstacles
* NBC Contamination

Each of the environmental factors involves problem areas and potentially useful AI/robotics concepts. These are summarized in Table 16.

Variations in elevation and vegetation are terrain factors that frequently limit the line of sight. This, in turn, limits employment of weapons, and the use of line-of-sight communication systems, which have natural advantages against EW threats. The Aerial Observer/Designator and the Adaptive Airborne Communications Relay are concepts that could alleviate these problems.

Table 16

ENVIRONMENT IMPLICATIONS

Environmental Factors	Problems and Implications for AI/Robotics	Application Concepts
Terrain	Line-of-sight limitations	Aerial Observer/ Designator
	Rough terrain trafficability	Adaptive Airborne Communications Relay
Climate	High/low temperature work degradation	Soldier's Slave
	Arid area water sources	Water Finder
Visibility (fog, smoke, haze)	Multi-sensor integration	Multi-Sensor Data Assimilator
	Obscure scenes	Scene Interpreter/ Clarifier
Water obstacles	Support hasty crossing	River Reconnaissance System
		Semi-Autonomous Assault Raft
NBC contamination	Rapid, safe reconnaissance	NBC Reconnaissance Robot
	Rapid decontamination	Vehicle Decontaminator
	MOPP/soldier labor	Soldier's Slave

The Army must be prepared to operate in areas with widely varying climatic conditions. The degradation of soldier performance in extreme high or low temperature conditions can reduce effectiveness of forces drastically. The Soldier's Slave would be able to perform a wide variety of heavy work tasks under such extreme conditions. In some areas, such as the Middle East, the overall arid climate severely limits the availability of water. Water is critical to the soldier--and to some of his equipment. In such areas, limited sources of water are available from sources that would not normally be recognized. An expert

system to advise soldiers attempting to find water could alleviate this problem.

Battlefield visibility is frequently obscured due to natural or man-made causes. Fog, haze, and dust are often present. Man-made obscurants can effectively limit visibility across a wide spectrum including the infrared and ultraviolet. As a consequence, many types of sensors are used in today's Army, and this diversity is increasing. Integrating and interpreting data from multiple sensors is an area in which AI approaches offer potential benefits. (In fact, this is an area to which AI research has already been directed.) In combination with vegetation, minor visibility impairments can cause a complex visual scene, in which it is extremely difficult for the soldier to detect, and identify objects of interest. The Scene Interpreter/Clarifier could aid the soldier in this area.

Water obstacles ranging from small streams to large lakes present significant impediments to the maneuver of ground units. River crossing operations are particularly complex, difficult and hazardous for Army combat units. The rapidly moving, widely dispersed unit battlefield conditions visualized in the Air-Land Battle 2000 study suggest that isolated units will be forced to conduct hasty crossings, without the extensive preparation and support associated with deliberate crossing operations. Two concepts could assist in this area: the River Reconnaissance System, to perform rapid water reconnaissance, and the Semi-Autonomous Assault Raft.

The capabilities of the Soviet Union to employ chemical and nuclear weapons on the battlefield are well recognized. In addition to their immediate destructive effects, these weapons can create extensive areas of contamination. In order to avoid casualties, Army units must either avoid such areas, or adopt protective measures that seriously degrade performance. The mission-oriented protective postures (MOPP) vary for different situations, but, in all cases, operations are impaired. The soldier wearing full protective equipment simply cannot perform heavy work for a long period of time. The Soldier's Slave could greatly aid

in this area, and could also reduce the hazards to soldiers associated with leaving protected environments such as vans or CP shelters. Rapid reconnaissance is necessary if contaminated areas are to be avoided. The NBC Reconnaissance Robot could fill this need. Finally, combat equipment such as tanks must be rapidly decontaminated after exposure to chemical attack or contamination. The present slow, hazardous methods of performing such decontamination operations could be greatly improved by a Robotic Vehicle Decontaminator.

2.2.5.2. Environmental Design Requirements

Military equipment must be designed to withstand many environmental extremes and to operate in the field under adverse conditions. It is quite obvious that systems designed for use in a factory environment would not be suitable for the military environment. It is less obvious that development of technical approaches that produce the best robot for use in a benign environment may not be the best approaches, or even suitable approaches, for devices intended to operate in a military environment. The need to meet environmental requirements must be recognized early in the R&D process--not deferred with the expectation that band-aid approaches can solve these problems after the basic development work is completed. Four general areas are of particular concern. They are:

* Day/Night/All-Weather Operations--System designs must not anticipate operation under well lit, dry conditions and moderate temperature domains.
* Conventional and NBC Hardening--In addition to the obvious needs for some degree of protection from normal weapon effects, two aspects of hardening bear particular attention. Electrical and electronic systems are highly vulnerable to the electromagnetic pulses associated with nuclear weapon bursts. Approaches that provide good protection against such effects are available. Many materials commonly used in the fabrication of equipment are not compatible with chemical agents and decontaminants.
* Environmental Engineering--Systems must be able to withstand factors such as vibration, shock, humidity, dust, and storage in extreme temperatures.

* Reliability-Availability-Maintainability (RAM)--The normal military requirements for RAM are far beyond the demands of most factory applications. Approaches that are suitable for the factory may be inherently unsuitable for meeting these requirements.

The essential point to be made is that the rapid emergence of this technology suggests that exploratory development efforts specifically focused on solving environmental problems as they pertain to AI/robotics are needed, not that AI/robotics systems cannot be fielded for a military environment. Lack of such early programs may cause eventual severe delays or setbacks in Army efforts to field applications for combat and combat support.

2.2.6. Personnel

In the course of all of the analyses discussed in the preceding sections, it repeatedly appeared that many of the problem areas and potential applications were influenced by manpower and personnel considerations. In the numerous discussions of problems and potential applications with Army agencies, which occurred during the study, manpower and personnel issues also were frequently raised.

These manpower and personnel problems suggest four major ways in which AI/robotics could contribute to solving manpower and personnel problems. These areas of contribution can be viewed as personnel thrusts for AI/robotics. They are:

* Hazardous Situations--Assist the soldier in performing required tasks in hazardous situations.
* Augment Manpower--Multiply the combat power contribution of soldiers by augmenting their roles in combat and combat support. Ultimately, this may involve replacing soldiers in some tasks.
* Enhance Capabilities--Enhance the soldier's ability to perform difficult or complex tasks.
* Simplify Interfaces--Simplify the soldier-machine interface involved in high technology systems.

Each of these personnel thrusts implies more detailed problems and potential AI/robotics concepts. These are shown in Table 17.

Table 17

PERSONNEL THRUST IMPLICATIONS

Personnel Thrusts	Problems and Implications for AI/Robotics	Application Concepts
Hazardous situations	Avoid direct and indirect fire	Infantry Robotic Grenade Homing Tank Killer Infantry Precursor Street Walker Scout Soldiers Auxiliary Eye
	NBC survival	NBC Sentry Vehicle Decontamination Contaminated Casualty Handler
Augment manpower	Multiply soldier combat power	TEARS/DEMONS Light Fighting Sentry Heavy Fighting Sentry
	Perform support tasks	Mine Emplacer Smoke Layer Cargo Handler
Enhance capability	Heavy or tedious tasks	Soldier's Slave Ammunition Handler
	Complex tasks	ASP Layout Planner Soldier's Movement Guide Emergency Repair and Maintenance Advisor
Simplify interface	Speech control	Speech Command Auditory Display System Voice Helicopter Control System
	Computer access	Division Commanders Quick Data-Access System

The primary hazards facing the individual soldier on the battlefield are direct and indirect fire weapons and NBC hazards. The concepts listed in Table 17 would all contribute to allowing the soldier to perform combat and combat-support tasks with a reduced exposure to these hazards.

Currently, the Army must maintain combat-ready forces under severe limitations on available manpower. In war-time, it is generally anticipated that the Soviet Union can deploy numerically superior forces. There is no reason to believe this situation will improve significantly in the future. Thus, it is important to augment the available manpower as much as possible to perform combat and combat-support tasks. This may take the form of placing one or more semi-autonomous systems under the control of a soldier, or in the longer term, replacing soldiers in certain tasks. The application concepts shown in Table 17 could contribute in this area.

Many tasks on the battlefield require heavy or tedious work. In many cases, such tasks amount to simple labor. The Soldier's Slave and the Ammunition Handler illustrate AI/robotic approaches to performing such tasks. Other tasks are highly complex. They demand extensive training, a high degree of intellectual ability, or an extensive background of experience. AI/robotics systems, as illustrated by the concepts shown in Table 17 could aid in this thrust--allowing soldiers with modest skills to perform complex tasks in a satisfactory manner.

The soldier-machine interface involves the understanding, operation, maintenance, repair, and control of equipment and the other resources of warfare, often under severe time constraints in very hazardous environments. As this interface becomes more sophisticated technologically, and the lethality of the battlefield increases accordingly, machines place an increasing demand on the individual soldier's presence of mind, intelligence, dexterity, stamina, and overall professional acumen.

Simplifying the interface between soldiers and machines can allow the soldier to concentrate his abilities on the elements of tasks for which humans are best suited, without requiring complex and time consuming interaction with equipment involved. The basic thrust is to allow soldiers to control machines or communicate with machines with a minimum of manual and intellectual effort devoted to the specifics of control and communication. The application concepts shown in Table 17

illustrate some ways in which AI/robotics can contribute to this process.

2.3. Summary

As a result of the analyses described in Section 2.2, and extensive discussion with Army agencies as described in Section 2.1, 100 concepts for C/CS applications of AI/robotics were developed. The concepts are listed in Table 18 and briefly described in Appendix A. The order in which they are listed is the same in Table 18 and Appendix A. The basis for the order is explained in Section 4.1, Application Categories. Ten concepts selected as category examples are explained in detail in Section 4.2, Category Examples.

As listed, the concepts represent a synthesis of many more ideas, which varied somewhat in minor features, primary purpose, or degree of technological advancement. In some cases, they are closely akin to concepts that have been previously studied or are planned for study in the near future. In other cases, they represent new ideas. The concepts have been deliberately formulated in a manner consistent with feasible technology advances, rather than within the current state of the art. In most cases, it would be possible to pursue much less sophisticated versions of the concepts in the near future.

Table 18

AI/ROBOTICS APPLICATION CONCEPTS

Human/Equipment Interface Aids
- Speech Command Auditory Display System
- Voice Helicopter Control System
- Scene Interpreter/Clarifier
- Multi-Lingual Order Generator
- Division Commander's Quick Data-Access System

Planning and Monitoring Aids
- Mission Execution Monitor
- Signal Array Planner
- Weapon Selection Planner
- Missile Launch Planner/Controller
- River-Crossing Planner
- Covering Force Maneuver Planner
- ASP Layout Planner
- Brigade Mission Planning Aid
- Soldier's Movement Guide
- Nuclear Fire Planner

Expert Advisors
- Emergency Repair and Maintenance Advisor
- Missile Launch Trouble Shooter
- Combat Vehicle Service and Survival Advisor
- EOD Advisor
- Water Finder

Data Assimilation and Access Aids
- Interrogation Support System
- C^2 Database Query Language
- Route Planning Aid
- Combat Vehicle C^2
- Imagery Interpretation Aid
- Adaptive Database Reconfiguration System
- Multi-Sensor Data Assimilator

Handling Support Systems
- Artillery Loader
- Tank Ammunition Handler
- Tank Gun Loader
- Contaminated Clothing Hnadler
- Contaminated Casualty Handler
- Cargo Handler
- Multi-Purpose Manipulator
- Refueler
- Vehicle Recovery Aid
- Ammunition Handler
- Helicopter Missile/Rocket Reloader
- Nuclear Munition Outloader

Support Systems
- Vehicle Decontaminator

- Armor Resupply and Service Vehicle
- Line Charge Layer
- Semi-Autonomous Assault Raft
- Air Robotic Platform
- Ground Rootic Platform
- Combat Vehicle--Support Slave
- Combat Porter
- Mine Emplacer
- Soldier's Slave
- Reconnaissance Robot
- Remote Communication Relay
- Adaptive Airborne Communication Relay
- Smoke Layer
- Infantry Precursor
- Armor Precursor
- CP Antenna Remoting System
- Man-Packed Portable Deception System
- EOD Assistant
- Airborne Minefield Detection System
- Barrier Emplacement Aid
- Remote Adaptive Jamming System
- Mine Clearer

Situation Assessment System
- Brigade Situation Analyzer
- Artillery Movement Assessment System
- Tactical Threat Projection System
- Super Sextant
- Chemical Hazard Warning Analyzer
- Deceptive Identification System

System Controllers
- Line-of-Sight Controller
- Safe Return Controller
- Fire Allocation and Control System
- IFF Module
- Copilot
- Armor Hit Avoidance System
- Helicopter Automatic Target Acquisition System
- EW Equipment Controller
- Communication Network Manager
- Adaptive EW Control System
- Target Acquisition and Homing Device
- Target Acquisition/Allocation System

Weapons
- Tears/Demons
- Light Fighting Sentry
- Heavy Fighting Sentry
- Close Air Defense Sentry
- Homing Tank Killer

Information Collectors
- River Reconnaissance System
- NBC Reconnaissance Robot
- Aerial Observer/Designator

Ground Observer/Designator
Remote Scene Analyzer
EW Sentry
NBC Sentry
Wire Tapper
Street Walker Scout
Approach Sentry
Leach Armor Marker
Multi-Purpose Sensor Emplacer
Tactical Reconnaissance Robot
Soldier's Auxiliary Eye

It should be recognized that the development of these concepts involved only enough effort to recognize that they would be useful in terms of solving or alleviating Army problems. None of the concepts was analyzed in sufficient depth to clearly understand whether or not the Army should or should not pursue them in the stated form. Overall, the concepts form a body of useful ideas, and a collection of adequate breadth to cover the potential of AI/robotics for combat and combat support.

In addition to specific application concepts as listed in Table 18, the analyses led to some insights of a more general nature that should be considered in planning AI/robotics R&D. These pertain to militarization, evolutionary approaches, modular approaches, and countermeasures.

Militarization involves problems of guiding emerging AI/robotics technology from the factory to the battlefield environment. These are discussed in some detail in Section 2.2.5.2. Exploratory development efforts related to such areas as day/night/all-weather operation, conventional and NBC hardening, environmental engineering and RAM are needed to avoid serious delays or setbacks in Army efforts to field applications.

The Army does not have any experience with fielded AI/robotics systems to use as a guide for the many judgments involved in system development. This suggests that an evolutionary approach should be followed--beginning to field systems that are within the current state of the art and using the experience gained with such systems as an

ingredient of future development programs. There are three specific ways in which such evolution should occur.

* Increasing Autonomy--Systems can evolve from remote control or very limited semi-autonomy (which is within the current state of the art), to fully autonomous versions.
* Increasing Flexibility--Single-purpose systems can evolve into multi-purpose systems.
* Increasing Distribution--Very limited production and distribution of trial systems can precede Army-wide fielding of large quantities of equipment.

Many applications require similar AI/robotics modules, such as vision or legged locomotion. In addition, it appears that some concepts can be structured as different versions of the same basic system. Work toward achieving commonality of modules early in the development plan can contribute to better and cheaper progress in the future. Some specific areas in which such modular approaches could be pursued are:

* Basic mobile carriers
* IFF modules
* Multi-purpose expert system frameworks
* General-purpose planning support modules
* Sentries with varying armament and purpose.

Early work is needed on countermeasures as they apply to AI/robotic applications. An understanding of both the countermeasures that any enemy might employ, and the feasible active and passive counter-countermeasures is a necessary ingredient for developing truly effective systems. In addition, it is important for the U.S. to begin to consider what countermeasures might be effective and needed against a potentially significant Soviet AI/robotics combat threat.

3. ARTIFICIAL INTELLIGENCE AND ROBOTICS

3.1. Introduction

To be able to perform human tasks, an intelligent robot should be able to think, sense, and effect (move and manipulate). The thinking of "brain function," executed by a computer, is the domain of artificial intelligence. Sensing and effecting are "body functions;" they are based on physics, mechanical engineering, electrical engineering, and computer science. Planning and execution of tasks entail both brain and body, and so are affected by both artificial intelligence and robotics. We will not attempt to distinguish between artificial intelligence and robotics but will present a model that encompasses both.

There are two basic goals of the research in these areas: to make computers smarter and to improve our understanding of human intelligence. The latter is also sometimes called "cognitive science" or "cognitive psychology." These two goals do not necessarily conflict, and, in fact, many researchers work toward both. For the purposes of this report, we will concentrate on research with the goal of making computers smarter.

Artificial intelligence and robotics are really in their infancy, but their promise is great. Some practical applications of this research are appearing, although in most cases they are limited and aimed at solving specific problems. Current research is directed towards both extending the capabilities of current applications and finding more general solutions to the problems they address.

In this section we will outline the current state of artificial intelligence and robotics and the basic research issues being addressed. We will focus on some of the problems that must be solved before certain aspects of intelligence will be available in computers. In Section 5,

we will make some predictions about future capabilities, the time and effort they will require, and the associated risks. A bibliography organized by subject area appears in Appendix A. Individual research will generally not be cited in this section.

Before discussing what artificial intelligence and robotics is, we will briefly mention who is doing research in these areas and where.

3.2. Background

The number of researchers in artificial intelligence and robotics is rapidly expanding with the increasing number of applications and potential applications of the technology. This growth is not only in the United States, but worldwide, particularly in Europe and Japan.

Basic research is going on primarily at universities and some research institutes. Originally, the primary research sites were MIT, CMU, Stanford, SRI, and the University of Edinburgh. Now, most major universities include artificial intelligence and/or robotics in the computer science curriculum.

An increasing number of other organizations either have or are establishing research laboratories for artificial intelligence and robotics. Some of them are conducting basic research, others are primarily interested in applications. These organizations include: Xerox, Hewlett-Packard, Schlumberger-Fairchild, Hughes, Rand, Perceptronics, Unilever, Philips, Toshiba, and Hamamatsu.

Also emerging are companies that are developing artificial intelligence and/or robotics products. U.S. companies include: Unimation, Cincinnati Milacron, MIC, Automatix, Teknowledge, Intelligenetics, Cognitive Systems, Artificial Intelligence Corp, Symantec, and Kestrel Institute.

3.3. A Unified Model for Artificial Intelligence and Robotics

Figure 2 can be viewed as a simplified model of an intelligent system. We will use it as a model for artificial intelligence and robotics. The major components are:

* Sensing
* Effecting
* Interpreting
* Generating
* Reasoning

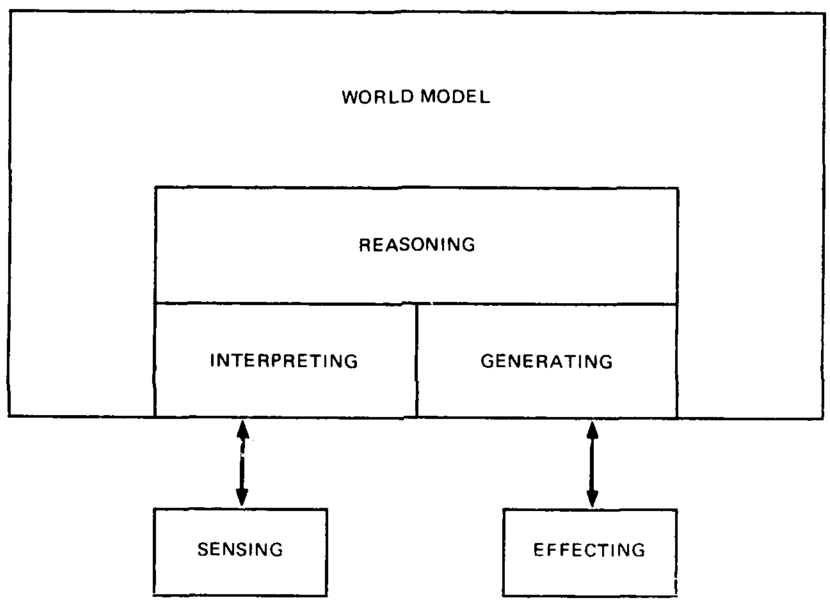


FIGURE 2 A UNIFIED MODEL OF ARTIFICIAL INTELLIGENCE AND ROBOTICS

The last three of these draw heavily on knowledge about the world and how it works. The parts of the model should not be viewed as isolated pieces, but rather clusters of related functions. We will describe the model briefly here and discuss the components in more detail in the following sections.

This model of artificial intelligence and robotics emphasizes intelligent functions that are performed. Underlying them are more fundamental research issues that are concerned with:

* Representing the knowledge needed to act intelligently
* Acquiring knowledge and explaining it effectively
* Reasoning: drawing conclusions, making inferences, making decisions
* Acting with knowledge that is incomplete, uncertain, and perhaps conflicting
* Evaluating and choosing among alternatives.

Advances in artificial intelligence and robotics require advances in these fundamental areas and the capabilities of intelligent functions (e.g., vision). In the discussion of technology gaps in Section 5 we will include gaps in both levels: the functional level and the fundamental level.

3.3.1. Sensing and Effecting

Sensing and effecting, the parts of the model at the bottom of in Figure 2, are primarily directed towards interacting with the environment. Sensing includes activities such as seeing, hearing, touching, smelling, and measuring distance. Effecting includes moving, object handling, and speaking. A characteristic of these actions is that they depend on heavy interaction with the environment, but very little (if any) ability to reason about it. They basically collect information, or produce information or action.

Sensing covers the basic input to a system with perhaps some limited processing that is performed independent of the use of the information. Input can be in many forms: pictures, radar, data, speech, typed input, and graphical input (charts, maps). This part includes simple processing, but nothing that requires any knowledge about the content of the input or the reasons for gathering it. For example, we might include format tracking on a speech wave as part of sensing, but not word identification. Similarly, some simple edge-detection methods would fall in this area if they only work on local changes in the digitized image and do not require information about the objects or background.

Companion to sensing (input) is effecting (output), that is, producing some signal/information or moving about. Again, some of the topics here are concerns of artificial intelligence and robotics, others fall under other disciplines. Under effecting we include systems that perform with some local control, but do not 'reason' about what they are doing. Effectors can be manipulators (hands, arms), legs, wheeled vehicles, and various means of communication (e.g., sounds, graphics, and pictures).

Some aspects of these areas are concerns of artificial intelligence and robotics, others are concerns of disciplines such as physics, mechanical engineering, electrical engineering, and computer science. We will focus on topics that are concerns of robotics or artificial intelligence.

3.3.2. Knowledge About the World

In any sophisticated interaction with its environment, an intelligent system must have some knowledge about that environment including:

* What objects are, or could be, around, e.g., trees, rocks, lakes, rivers, people, vehicles
* Actual and possible properties of the objects, e.g., size, shape, color, texture
* Their possible relationships with other objects, e.g., above, below, behind
* Changes that can occur and how they affect the situation, e.g., cutting down a tree destroys it; repairing a jeep makes it usable.

As we have mentioned, questions about how to represent, acquire, and explain this knowledge in a computer system are part of the fundamental research in artificial intelligence and robotics.

The parts of the model we call interpreting, generating, and reasoning all require some knowledge about the world. Furthermore, they all use that knowledge for some purpose, such as,

* Understanding the environment, e.g., recognizing and locating objects, and detecting changes in the environment

* Planning and carrying out actions to affect the environment, e.g., assembling objects, moving about.

3.3.3. Interpreting

Interpreting information is the means by which an intelligent system understands its environment. The information can be acquired through perceptual processes or other means (e.g., a database). We will focus on interpreting images, both visual and those provided by other sensors (e.g., radar, sonar) and interpreting language (written or spoken).

Images are interpreted for many reasons including: detecting, recognizing, and locating objects, detecting change (e.g., movement of objects), and describing unknown objects. Research is directed towards better methods for acquiring images, extracting information from the images and using knowledge about the objects.

There are two main reasons for developing computer systems that can interpret language: to improve a person's interaction with the machine and to facilitate the processing of textual information by a computer. For example, a person may interact with a computer in order to give it commands, query various databases, or conduct a dialog with some advice-giving system or teaching system.

Textual information may be processed in order to translate it, summarize it, or perhaps integrate it with other information. In each case the information must not just be 'read' but in some sense 'understood'.

3.3.4. Generating

The part of the model labeled 'generating' refers to the processes by which an intelligent system decides to influence its environment. This effect may be through direct or indirect action. Direct actions include manipulating objects, using hands and arms to assemble objects, and navigating a vehicle, avoiding obstacles and possibly replanning paths.

Examples of indirect actions include generating language and/or pictures in order to convey information to a person (or another system). The concerns of language and graphics generation are basically deciding what to say, and how best to say it.

3.3.5. Reasoning

The ability to cope with unforeseen, incomplete, uncertain, and perhaps conflicting information and to act and react to it is a prerequisite of any intelligent behavior. This ability is what we have labeled as reasoning in the final part of the model. Basic research is directed toward discovering and developing the underlying mechanisms necessary for reasoning.

Intelligent systems reason for many purposes, these include:

* Helping interpret sensory information
* Helping decide what effectors and sensors to use and how to use them
* Planning actions and monitoring their execution
* Solving problems
* Gathering new information
* Diagnosing a situation
* Recognizing a situation.

In the sections on interpretation and generation, we will discuss reasoning as it is used for interpreting and generating information. In Section 3.8 we will discuss other uses of reasoning and the research problems associated with developing computer systems for them.

3.4. Sensing

A wide variety of devices can be used by an AI/robotic system to obtain information. They include not only transducers for physical quantities, such as microphones for sounds, but data processing input devices such as keyboards for textual information and specialized military sensors such as NBC contamination detectors. In this report we treat all these devices as different kinds of sensors.

For military applications there is an important distinction between sensors that emit energy or matter (active sensors) and those that dqo not (passive sensors). Passive sensors are preferable when stealth is required.

The act of sensing is, in general, performed in two steps:

(1) Transducing--converting the energy, physical condition, etc. that is to be sensed into a signal, usually electrical.

(2) Preprocessing--improving the signal by noise reduction, averaging, filtering, data compaction, and the like.

While transducing methods are usually highly specialized to one type of external condition or influence, preprocessing methods are often generally applicable to signals from many different kinds of transducer.

3.4.1. Important Sensors for Robotics

Omitting sensors for which development is already strongly driven by military or data-processing needs, such as radar or keyboards, the most important types of sensors for robotics are solid-state television cameras, range sensors, tactile sensors, and proprioceptors. The following sections each discuss the state-of-the-art of one of these sensors in terms of capabilities and limitations of commercially-available equipment. They then describe advanced prototypes now in laboratories, and extrapolate future developments. In Section 3.5 we will discuss "interpretation" -- the problems associated with understanding the environment from sensor information.

3.4.2. Visual Sensors

Visual sensors, using television cameras, are needed for seeing what is around the robot. For robotic applications, solid-state cameras are preferred over those with vacuum-tube imagers such as vidicons because of their ruggedness, low image distortion low power requirements, and small size.

Today's solid-state television cameras can operate on visible light, or infrared. The highest image resolution available (800 by 800 pixels) is now about twice that of broadcast television, and the fastest cameras can take 2,000 pictures per second (as compared to 30 for broadcasting). Some imaging chips can even do simple image processing operations themselves, such as edge enhancement.

The main limitation of present-day solid-state cameras is that (except for one made by Hitachi) they do not take color pictures. Another problem is that they produce information much faster than a large conventional computer can process it, and most of it is highly redundant and uninformative.

Laboratory prototype camera chips now do some global image processing, such as fourier transforms. Nondestructive-readout cameras can store an image for hours and the image can also be modified by a computer while it is stored.

2000-by-2000-pixel resolutions should be available within about ten years. But, to reduce the amount of image data to be processed, some cameras may have only a small high-resolution region near the center of their field of view ("foveal cameras").

3.4.3. Tactile Sensors

Tactile sensors either detect when the hand touches something, or they measure some combination of force and torque components that the hand is exerting on an object. They usually use a number of strain gauges as transducers. However, a wide variety of simple, inexpensive devices such as microswitches can be used if it is only necessary to sense touch.

Force/torque sensors today use about eight strain gauges to measure the direction and magnitude of a force up to about 50 pounds with an accuracy of about one ounce. They can simultaneously measure the torque in any direction with comparable accuracy.

Today's force/torque sensors are too insensitive to handle objects lighter than a few ounces. They are also too large for use on miniaturized robots, are rather delicate, and are expensive ($3,500-$8,000). Commercially-available touch sensors are not especially designed for use on robots.

Arrays of pressure sensors have been fabricated with about two sensors per mm resolution in two dimensions.

Materials such as carbon fibers, fiber optics, and doped plastic films may make possible large, flexible sheets of artificial "skin" with embedded touch (or other) sensors.

3.4.4. Range Sensors

Range sensors are an important means of determining where objects are with respect to the robot.

In-air acoustic range sensors are accurate to about one millimeter over several meters. Laser range finders are accurate to about one meter over a kilometer; with a retroreflector on the target, however, they can easily measure to about a millimeter accuracy.

The main drawback to current range finders is that they must be scanned slowly over a scene in order to determine the 3-dimensional shape of the terrain and objects. The transverse resolution (beamwidth) of acoustic rangers and the range resolution of laser rangers is too coarse to be useful in many manipulation tasks.

A scanning laser ranger has been developed that simultaneously measures the reflectance of an object as well as its distance. This produces precisely-registered range and intensity images.

Electro-optical devices that operate in picoseconds are now being developed. These promise to improve the resolution of laser rangers to a few millimeters without the need for a retroreflector on the target object.

3.4.5. Proprioceptors

Proprioception in robotics means sensing the posture of a mechanical manipulator, leg, or other jointed mechanism. This is used mainly in two ways: in controlling the mechanism whose posture is sensed, and in sensing the posture of a teleoperator master arm in order to command the motion of a slave arm.

Proprioception involves measuring the angle of each rotary joint and the extension of each telescoping joint in a mechanism. The joint position sensors are usually either potentiometers, resolvers, or encoders.

Today, joint position sensors are accurate enough to enable a six-joint manipulator to place its hand anywhere within a three-meter-radius working volume with one-millimeter accuracy.

Highly-accurate sensors for joint angles or extensions are delicate, expensive, and difficult to manufacture. They are also too large for use in miniaturized robots.

In future, it may prove easier to measure the position of the hand directly than to infer it from accurate measurements of each joint position.

3.5. Output/Effectors

As we did for sensor technology in the preceding section, we will first list the important robotic effectors, then describe the state of the art and extrapolate future progress for each. In Section 3.7 we will discuss "generation" -- the problems associated with using these effectors intelligently.

3.5.1. Important Effectors for Robotics

Omitting effectors for which development is already strongly driven by military or data-processing needs, such as weapons or displays, the most important types for robotics are devices that produce certain types of motion. It is convenient to group them loosely into "legs" that move

the entire robot over the terrain, "arms" with a range of motion on the order of the size of the robot itself, and "hands" that are positioned by the arms and have a much smaller range of motion. All of these are strongly dependent on the important supporting technology of mechanical actuators -- electric, hydraulic, and pneumatic -- which we do not have space to treat in this report.

The following sections each discuss one of these effectors in terms of capabilities and limitations of commercially-available equipment. They then describe advanced prototypes now in laboratories, and extrapolate future developments. We will also discuss the control of locomotion systems in Section 3.7.1 and the control of hands and arms in Section 3.7.2.

3.5.2. Hands

Commercially-available hands today are usually clamps with two or three jaws. The jaws are most often operated pneumatically, so that they are always held either open or closed with full force. Most general-purpose grippers offered today can hold parts weighing up to ten pounds and up to a few inches across.

The main problem with commercial grippers is that they are too clumsy for anything but simple handling tasks. Most of them are only suitable for use on the smaller manipulators; hands for large manipulators usually have to be engineered for each different task.

A three-fingered hand with three joints per finger has been built in an attempt to provide the dexterity needed for complex manipulation tasks such as assembly. It has ten motors, tension-cable drives, and joint-torque sensing.

Visual and tactile sensors will be incorporated into robot hands. Hands will have built-in computers to coordinate the motions of their fingers in order to grasp objects and move them precisely.

3.5.3. Arms

More than a hundred different companies around the world now make manipulator arms. They range in size from tiny arms for handling near-microscopic hybrid circuit components up to machines that can lift objects weighing several hundred pounds four or five meters into the air. Typical positioning accuracies are about one millimeter and speeds about one or two meters/second.

Older arms resemble a tank turret with a hand on the end of a telescoping gun. Modern ones usually have five or six rotary joints in series, and move in somewhat the same way as a human arm does. Recently, several "Cartesian" manipulators have appeared on the market that have three orthogonal sliding joints for rigidity and ease of control. An arm is usually designed for a particular type of activity such as spraying, simple handling, or precise assembly.

Today's arms are expensive, complex, heavy, inefficient, and weak for their size. Arms that are good for a task like spraying are not suitable for precise assembly.

A prototype arm has been developed with improved actuators at the joints that eliminate the need for gearing (the "direct-drive joint"). Another arm is very compliant instead of being rigid like today's industrial arms.

The physical complexity of arms will decrease as ways are found to integrate joints, actuators, and sensors into the structure of the arm itself. New materials such as carbon fiber composites will lead to lighter, stiffer arms that can move more quickly and accurately with less effort. "Elephant trunks" that have a large number of joints will be built for getting into tight places. Micromanipulators will be developed for handling very small objects. Teleoperator master controls will be developed that are smaller, cheaper, and more convenient to use than the "full-scale model" ones in use today.

3.5.4. Legs

By "legs" we mean not only mechanical legs, but all the conventional locomotion methods now used by Army platforms, such as wheels, tracks, wings, and boats. Although each of these will be a very important means of locomotion for military robots, the technologies for conventional locomotion are strongly driven by other needs. Therefore, we will not discuss them here, but concentrate on mechanical legs. Furthermore, since there are no commercial versions of mechanical legs on the market at present, we omit discussion of their capabilities and limitations and begin with laboratory prototypes.

Mechanical legs may prove very useful in certain terrain conditions that defeat other locomotion methods. The technology is still in its infancy, however.

Several robots have been built in laboratories around the world that walk on two legs, four legs, and six legs. The simpler models merely drive the legs without regard to terrain or body attitude. The more advanced models control the torques exerted by each leg joint to respond to instantaneous conditions.

Practical mechanical legs will be developed. They will probably require significant advances in actuator technology, since they will at least have to outperform present-day manipulators in terms of strength to weight ratio.

3.6. Interpreting

In this section we will discuss artificial intelligence and robotics research associated with interpreting sensory information, covering the areas of

* Computational Vision
* Natural Language Understanding (spoken or written)

3.6.1. Computational Vision

The general goal of computational vision is developing mechanisms for interpreting visual images. Interpreting images can be described as the process of going from a video (or other) signal to a symbolic description of it. (A symbolic description might be "That is a forest" or "A man is standing by the rock.") The same image may, in fact, have many descriptions depending on the reasons for processing it. One goal may be to count all the objects in an area, another may be to describe them, another may be to determine their exact location (without identifying them), and another to find irregularities in the terrain that can pose navigation problems.

Among the reasons for interpreting images are:

* Identifying objects
* Locating objects
* Detecting changes
* Navigating
* Describing a scene
* Making maps and charts.

3.6.1.1. Current Status

We will cover the current state of computational vision in three areas: commercially available devices, systems and techniques that are undergoing laboratory development or testing, and basic research problems.

The commercial systems that are available are principally for industrial use. Suppliers include Machine Intelligence Corporation, Automatix, General Electric, and Bausch and Lomb. These systems can identify and locate objects in a controlled environment with the following restrictions:

* The number of possible objects that can be identified is limited.
* The number of objects in the scene is limited.

AD-A118 297 SRI INTERNATIONAL MENLO PARK CA F/G 6/4
R&D PLAN FOR ARMY APPLICATIONS OF AI/ROBOTICS.(U)
MAY 82 D R BROWN, D V FOWLER, D J FRIE DAAK70-81-C-0250
UNCLASSIFIED ETL-0296 NL

2 of 4
A
118297

* The objects do not overlap.
* The object is always viewed vertically.
* The image features of an object are extracted from its binary image (silhouette).
* The objects are illuminated so as to obtain high dark-to-light contrast.

Typically, a system is trained to distinguish among objects by showing it sample objects. It will find outlines of each object and, using various techniques, develop a classification so it can distinguish the different types.

More sophisticated processing techniques for identifying and locating objects are being developed and tested in laboratories. For example, instead of requiring that the entire outline of an object be visible, some knowledge about the shape of the objects is used to "fill in" any edges that may be obscured by objects, shadows, or perhaps poor lighting. Other techniques include:

* Use of gray-scale information
* Use of 3-dimensional information
* Use of color, texture, and other attributes.

In general, this research will lead to more flexibility in the images that can be processed, including the following capabilities:

* Identifying objects that overlap
* Accommodating for a change in perspective
* Fewer requirements on lighting conditions.

In addition to industrial devices, systems for interpreting images for purposes other than industrial automation are in the laboratory stage. Two such areas are the automatic or semi-automatic interpretation of aerial imagery, e.g., for cartography and the interpretation of chest x-rays.

The development of these systems can be viewed as a movement in the diagram in Figure 2 from sensing (simple processing of sensory input) to interpreting as more knowledge about the objects in the images and procedures for using it become incorporated.

Basic research in computational vision is devoted to understanding how further knowledge and reasoning can be used to interpret images, particularly so-called 'natural scenes', such as those found outdoors, where there are no restrictions on the environment, the objects, or the lighting.

Two major thrusts can be seen in current research. They are generally referred to as high-level vision and low-level vision.

High-level vision is concerned with combining knowledge about objects (shape, size, relationships), expectations about the image (what might be in it), and the purpose of the processing (identifying objects, detecting changes) to aid in interpreting the image. This high-level information interacts with, and helps guide, processing. For example, it can suggest where to look for an object, and what features to look for.

Low-level vision is concerned with extracting local data without the use of more general types of knowledge. This includes the problems associated with determining the physical characteristics of objects and scenes and how they influence perception. Physical properties include: surface reflectance, surface orientation, and incident illumination.

3.6.1.2. Research Issues

Although vision systems are becoming available, there are many remaining research problems. They include:

* Representing knowledge about objects, particularly shape and spatial relationships
* Developing methods for reasoning about spatial relationships among objects
* Understanding the interaction between low-level information and high-level knowledge and expectations
* Interpreting stereo images, e.g., for range and motion
* Understanding the interaction between an image and other information about the scene, e.g., written descriptions
* Determining terrain features: lakes, pebbles, mud, quicksand.

3.6.2. Natural Language Interpretation

Research on interpreting natural language is concerned with developing computer systems that can interact with a person in English (or another nonartificial language). One primary goal is to enable computers to use human languages rather than force humans to use computer languages.

Research is concerned with both written and spoken language and, although many of the problems are independent of the communication medium, the medium itself can present problems. We will first consider written language, then the added problems of speech.

There are many reasons for being able to develop computer systems that can interpret natural-language inputs. They can be grouped into two basic categories: improved human/machine interface and automatic interpretation of written text.

Improving the human/machine interface will make it simple for humans to

* Give commands to the computer--or robot
* Query databases
* Conduct a dialog with an intelligent computer system.

The ability to automatically interpret text will enable the computer to

* Produce summaries of texts
* Provide better indexing methods for large bodies of texts
* Translate texts automatically or semi-automatically
* Integrate text information with other information.

3.6.2.1. Current Status

Natural language understanding systems that interpret individual (independent) sentences about a restricted subject area (e.g., data in a database) are becoming available. They can accept sentences whose grammar is complex, with a reasonably large vocabulary, about a

restricted subject area (e.g., the subject area covered by the data base). Their major limitation is that they cannot interpret a sentence whose meaning depends on the more general, dynamic context supplied by preceding sentences.

Commercial systems providing natural-language access to databases are becoming available. Given the appropriate data in the database they can answer questions such as:

* Which utility helicopters are mission ready?
* Which are operational?
* Are any transport helicopters mission ready?

However, these systems have limitations, among which are:

* They must be tailored to the database and subject area.
* They only accept queries about <u>facts</u> in the database, not about the contents of the database, e.g., "What questions can you answer about helicopters?"
* Few computations can be performed on the data.
* The meaning of a sentence cannot depend on the context.

So, for example, after asking:

What is the status of squadron A?

If the user asks

What utility helicopters are ready?

the utterance will be interpreted as

"Which among <u>all</u> the helicopters are ready?"

not

"Which of squadron A's helicopters are ready?"

Database access systems with more advanced capabilities are still in the research stages. These capabilities include:

* Easy adaptation to a new database or new subject area.
* Replies to questions <u>about</u> the contents of the database (e.g., what do you know about tank locations?).
* Answers to questions requiring computations (e.g., the time for a ship to get someplace).

3.6.2.2. Research Issues

In addition to extending capabilities of natural language access to databases, much of the current research in natural language is directed towards determining the ways in which the context of an utterance contributes to its meaning and developing methods for using contextual information when interpreting utterances. For example consider the following pairs of utterances:

> Sam: The lock nut should be tight.
> Joe: I've done it

and

> Sam: Has the air filter been removed?
> Joe: I've done it

Although Joe's words are the same in both cases, and both state that some action has been completed, they each refer to different actions. In one case, tightening the lock nut, in the other, removing the air filter. The meanings can only be determined by knowing what has been said and what is happening.

Some of the basic research issues being addressed are:

* Interpreting extended dialogs and texts (e.g., narratives, written reports) where the meaning depends on the context.
* Interpreting indirect or subtle utterances, such as recognizing that "Can you reach the salt?" is a request for the salt.
* Developing ways of expressing the more subtle meanings of sentences and texts.
* Interpreting language that is "ungrammatical", e.g., slang or dialects. (This is particularly of interest for spoken language.)

3.6.3. Spoken Language

Commercial devices are available for recognizing a limited number of spoken words, generally fewer than 100 words. These systems are remarkably reliable and very useful for certain applications.

The principal limitations of these systems are:

* They must be trained for each speaker.
* They only recognize words spoken in isolation.
* They recognize a limited number of words.

Efforts to link isolated word recognition with the natural language understanding systems are now underway. The result would be a system that, for a limited subject area, and with some training, would respond to spoken English inputs.

Understanding connected speech (i.e., speech without pauses) with a reasonably large vocabulary will require further basic research in acoustics and linguistics as well as the natural language issues discussed above.

3.7. Generation

We have defined generation broadly to include those topics associated with generating actions and language. Under that heading we will discuss:

* Mobility
* Manipulation
* Language generation.

3.7.1. Mobility

Mobility can include both navigation and propulsion. Since Section 4.2.11.3.3 contains a discussion of the problems associated with navigation, we will restrict our discussion here to propulsion.

Propulsion issues include the choice of a locomotion method and operation of the propulsion equipment, which involves input and output.

Conventional locomotion methods include all those used by current Army platforms -- wheels and tracks for ground locomotion, fixed and rotary wings for flight, propellers and pumps for water travel. Unconventional locomotion methods might include mechanical legs or

ground effect (hovercraft) equipment for ground travel, balloons for flight, fins for swimming, and tunneling equipment for subsurface mobility.

3.7.1.1. Current Status

Operating a locomotion system involves controlling the propulsion system and steering the vehicle. These tasks require different kinds of sensing and different computer control.

3.7.1.1.1. Capabilities

Controlling the propulsion system usually requires sensing conditions such as wheel slippage, and it can require rapid responses, such as control of ailerons. Interfacing the propulsion mechanisms to the controlling computer is a straightforward engineering task, but developing the software for controlling the mechanisms may be quite difficult. Some locomotion systems, such as common helicopters and laboratory legged vehicles, have such complex dynamics that controlling them automatically is currently impractical. Helicopter autopilots can only hover, for instance. Most walking vehicle research ignores two-legged and four-legged configurations and treats only the more stable six-legged case.

Steering involves sensing conditions immediately ahead of the vehicle, such as the direction of a road.* It requires somewhat slower responses, but correspondingly more computer processing.

3.7.1.1.2. Limitations

All current platforms have been designed for specific purposes and terrain and cannot operate in other situations. For example, flying RPV's (remotely piloted vehicles) cannot operate in forests or buildings, tanks may get trapped in ditches and their tracks may come

---

* Steering is often considered part of navigation and consequently is discussed in Section 4.2.11 also. However, since steering problems are directly related to the type of locomotion, we mention them here, too.

off on steep slopes, trucks may become bogged down in mud and snow, armored personnel carriers cannot cross rivers with steep banks or rapid currents.

In many cases, the range or speed of existing propulsion systems is inadequate. Tanks should not move between battlefields, but rather be carried on special air, rail, or ground vehicles. Battery-powered vehicles have limited range. Wheeled vehicles cannot travel as rapidly as tracked vehicles in mud or plowed fields.

Automatic steering methods are currently inadequate to keep a vehicle on a conventional road. Laboratory systems have followed specific types of roadway at slow speeds, by monitoring a specific feature such as a painted centerline or a high-contrast road edge. They are easily defeated by bad weather, debris, bridges, and different road surfaces.

Propulsion methods are needed that are suitable for use in

* Mud, bogs, swamps, sand, and soft ground
* Thick forests
* Narrow mountain trails
* Minefields, dry gaps, abatis, and other countermobility obstacles
* Wet gaps with steep banks, ice, and/or fast currents
* Built-up areas, including narrow streets, rubble, and interiors of buildings
* Tunnels, sewers, ducts, pipes, and other narrow channels

In addition, many applications will require highly miniaturized mobile AI/robotics systems. The smaller the vehicle, the more objects will be large enough to block its path, and the more important it will be to find high-mobility vehicle designs.

3.7.1.1.3. Laboratory Prototypes

Mobile robots of many types have been constructed. Some notable ones include the General Electric Walking Truck (a 4-legged vehicle teleoperated by an on-board operator), SRI's Shakey and the Hilare robot

of L.A.A.S. in Toulouse, France (two self-navigating, self-propelled wheeled robots), the Navy's free-swimming submersible, and a remotely-managed semi-autonomous drone aircraft. Cruise missiles might be included in this list, too.

Ohio State University (OSU) has conducted most of what little American research has been done so far on unconventional modes of locomotion (six-legged). Russia and Yugoslavia have also done significant work on the subject. Some years ago a Japanese laboratory developed prototypes of mechanical "snakes" and "limpets" that could enter confined spaces where no man or vehicle can go. More recently a different Japanese laboratory demonstrated a two-legged robot.

OSU is now coordinating a $5-million research program that involves six U.S. contractors and three foreign research centers in Japan, France, and Canada. They are to produce, initially, a six-legged, man-carrying, "active suspension vehicle" by October, 1984 that is energy-efficient, easy to drive, and can sense the shape of the terrain ahead and adapt to it automatically.

3.7.1.2. Research Issues

Recent laboratory research on mobility concerns such topics as sensorimotor learning, motion in fleets, steering wheeled vehicles, visual obstacle avoidance, and autonomous underwater robots. Since the kinematic equations change discontinuously whenever a leg reaches or leaves the ground, it has been quite difficult to develop conventional feedback control laws for legged devices. Operations research techniques such as linear programming seem to offer a more fruitful approach.

3.7.2. Manipulation

Manipulation is the use of mechanical arms and hands to move objects. Manipulation tasks can be classified in six different ways on the basis of certain of their characteristics:

(1) Application

(2) Complexity of sensing required

(3) Complexity of control algorithms required

(4) Type of hand or tool motion required

(5) Type of drive used by the manipulator's actuators

(6) Configuration of the manipulator's joints

Three important manipulator applications are (1) continuous material deposition, (2) rigid object handling, and (3) part mating.

Tasks may require three different types of sensing: (1) no sensing, (2) primitive sensing, or (3) complex sensing.

Five different levels of control complexity can be distinguished:

(1) Teleoperation

(2) Limited-sequence manipulation

(3) Teach/replay

(4) Computer-controlled

(5) Sensor-guided

Two main types of tool motion are needed in manipulation: point-to-point and continuous-path.

Commercial manipulators use one of three kinds of drive system today: (1) electric motors, (2) hydraulic actuators, or (3) pneumatic actuators.

Finally, manipulation tasks may be classified in three different ways according to the joint configuration of the manipulator: (1) all rotary, (2) a combination of rotary and Cartesian, or (3) a combination of rotary and prismatic joints.

Different applications require different kinds of manipulators. Spraying usually requires an arm with a long reach (about 3 m), medium speed (about 1 m/second), low accuracy (about 1 cm), smooth and continuous motions, and no sensory feedback. Decontamination of vehicles and equipment would be an important spraying job for a robot.

Simple handling often requires a long reach (1-6 m), although smaller arms are also used for this purpose. It also requires high speed (1-3 m/second), moderate accuracy (6 mm), intermittent or "point-to-point" motions, and simple sensory feedback if any. A typical simple handling job would be to load shells from a rack into a gun breech, where the rack and breech are in known positions with respect to the robot.

Dexterous manipulation tasks require heavy use of sensing and software, and are the most difficult kind. They usually require little reach (1 m) and moderate speed (1 m/sec), but very high accuracy (1 mm or better) and a variety of different types of motion (point-to-point, continuous, straight-line, sensor-controlled, compliant, etc.). Some difficult manipulation tasks are assembly, disassembly, handling loose or non-rigid objects, and cooperating with people in a manipulation task. An extreme example of a dexterous manipulation task would be the deactivation of a demolition charge. These tasks are difficult because of inherent uncertainties -- the objects involved might be damaged, unidentified, or not precisely positioned, for example. An intelligent robot might fail to perform a part of a task and have to try again or find a different way to perform it. Its sensors allow that robot to know what it is working on and when something goes wrong; its software allows it to decide what to do in response.

Arc welding requires sensing of the weld joint and appropriate software to control the motion of the weld gun as well as other parameters in the welding schedule. It requires low speed (15 cm/second) but high accuracy (2 mm).

Teleoperation is useful when a task has great variability from repetition to repetition, or when the task only needs to be done once. The task could be simple handling, a delicate assembly or disassembly operation, or some other kind. In teleoperation, a person is in the control loop, rather than a computer. The person operates the robot or "slave" arm and responds to the sensor signals. People have great ability to adapt to inaccuracies in the slave arm and to poor-quality

tactile or visual feedback from the work area. In such situations, a person can almost always complete a manipulation task much faster, more precisely, and with less chance of failure than a computer can.

3.7.2.1. Current Status

Teleoperators, limited-sequence manipulators, and teach/replay industrial robots have been available for about twenty years. Computer-controlled robots entered the marketplace about ten years ago. Commercial robots equipped with simple tactile and visual sensors have only become available in the last two years.

3.7.2.1.1. Capabilities

Thousands of robots all over the world now spray paint, palletize, spot weld, arc weld, cut, form, and inspect hundreds of different products. Many even operate other automatic machinery such as presses, molding machines, and numerically-controlled machine tools, just as people do.

For about five years now, commercial robot control software has been able to perform kinematic computations for a manipulator automatically. This means that one no longer has to manually coordinate the motions of all a manipulator's joints in order to make its hand move in a certain way. A typical computer-controlled manipulator today can automatically move its hand at a controlled speed in a straight line in any specified direction, move smoothly along a specified curved path, pass through a sequence of specified positions, control its hand orientation, etc. In particular, these kinematic computations allow it to adapt to arbitrarily-positioned workpieces and equipment. For example, a computer-controlled robot could insert a round into the breech of a gun that traverses or elevates between each round, provided the gun's displacements are made known to the computer.

Despite recent advances in sensing and control software, the vast majority of all robots still work on known objects that are held precisely in position for them. Most robots can make only the simplest

kinds of decisions, few can sense, and dexterous manipulation in factories is still very rare.

3.7.2.1.2. Limitations

Very few robots today have sensors. This makes it difficult for them to handle objects that are not precisely positioned -- if they are jumbled in a bin, for example, the robot cannot tell where to reach in order to grasp one. As another example, spraying robots today are all blind, so they can only spray objects that move precisely along a known path. A person can follow a swinging part with the spray gun, and make sure he doesn't miss any part of it. No robot can do this today.

Dexterous manipulation will require much better hardware than is currently available. A commercial gripper is an extremely clumsy device, usually just a clamp.

An industrial manipulator probably could not survive on a battlefield without some redesign. Some modifications that would be required are, for example:

* Militarize the computer. The controlling computer of most currently-used robots are not militarized. Either the computer would have to be militarized or replaced by a militarized computer with which the Army is already familiar. The latter choice would often require a complete rewrite of the control software, since most robot manufacturers use assembly language instead of a transportable high-level language.
* Shield the hydraulic lines. Commercial hydraulically-operated robots usually do not have their hydraulic lines routed through their joints, where they would be protected. This is partly because designing the joints is difficult enough without adding the requirement for a clear passage, too.
* Simplify its maintenance procedures. In a factory, routine maintenance of most robots can be performed by an electrician with a little training. However, major repairs such as replacing a broken gear must often be performed by the vendor's specialists. A military robot should be constructed from easily-replaceable mechanical and electronic modules, even if it makes the robot more expensive.

* Automate calibration procedures. Many commercial manipulators require a complex initial calibration procedure at the time they are installed. In some cases this procedure requires special tooling and the services of the vendor's specialists. Even after installation, some robots also require the user to carry out a somewhat simpler calibration procedure every time the robot is turned on. A military robot should be designed so that it can perform any necessary calibration procedures completely automatically --preferably without moving, for safety. These procedures could be combined with autodiagnostic checks, and performed whenever the robot is not busy.

Manipulator programming software today has many shortcomings. Although the "training" procedures used in simple handling tasks could probably be adapted for casual use by nonspecialist soldiers, today's robot programming languages (AL, VAL, RAIL, AML, etc.) are simply too difficult for them to learn and to use. Even a skilled programmer may require several hours to teach a robot to perform a task that he could tell a person how to do in less than a minute. To overcome this drawback the robot must be made more intelligent.

The most advanced robot control software in factories today is still not very "resourceful" or "smart" about recovering from errors. It has no "common sense." A person must describe in extreme detail how to test for mishaps, and say exactly how the robot should react. It is utterly impractical for that person to anticipate all possible errors and plan for the corresponding contingencies.

The rapid arm motions that are needed to perform many kinds of tasks efficiently add difficult dynamic control problems to the simpler kinematic ones. Although rapid computational methods to solve dynamics problems have been developed, no commercial manipulators use them yet; instead, manufacturers of robots overdesign their products and operate them inefficiently to make sure they will be stable and to prevent them from shaking themselves to pieces. Their speed could be increased and their cost, weight, and energy consumption could be decreased by using lighter material (e.g., graphite fibers), drives with higher power density (e.g., direct-drive joints with samarium-cobalt magnets), and better control software (e.g., that adapts to the arm's increasing moment of inertia as it reaches out.).

Teleoperation is often the only way to perform certain industrial tasks with a robot arm today. This is also true for many military applications, and will probably continue to be so for some time.

3.7.2.1.3. Laboratory Prototypes

Novel manipulators have been built with opposed tendons, direct-drive motors, and redundant degrees of freedom. A highly-ambitious three-fingered, nine-jointed hand with tactile sensing in each finger has been developed at Stanford University. Vision-controlled methods for handling objects supplied jumbled in bins have been developed at the University of Rhode Island. Research on hand-eye coordination, multiple arm coordination, tactile sensing, and robot programming languages has been in progress at Stanford University, SRI International, MIT, and Purdue for many years. Carnegie-Mellon University has recently set up a robotics laboratory, too.

Some American corporations developing advanced manipulators and sophisticated control systems for them include Unimation, Cincinnati Milacron, IBM, Texas Instruments, General Electric, Bridgeport Machine Tools, Thermwood, and IRI. Major foreign innovators include DEA and Olivetti in Italy, Kuka and Volkswagen in West Germany, Renault in France, and Hitachi, Fujitsu, Mitsubishi, and Kawasaki in Japan.

3.7.2.2. Research Issues

Practical solutions are not yet available for many important theoretical problems in manipulator control. These include:

* Planning a manipulator's motions so that it will not hit anything.
* Staying within the work space of the manipulator.
* Staying within the limited range of motion of each joint.
* Avoiding "joint flips" (an abrupt change from one arm posture to another for a small change in hand position).
* Avoiding "singularities" (arm postures for which the joints experience something akin to gimbal lock in a gyroscope).

* Finding fast or energy-efficient ways to handle objects.
* Rapidly moving a manipulator that has long and slender links without exciting oscillations in it.
* Controlling a "tentacle" manipulator that has dozens or even hundreds of joints.
* Automatically deciding how to hold an object for a secure grip, or in order to be able to use it properly (e.g., it should hold a gun by its stock, not its muzzle).
* Simulating the operation of a manipulator graphically so that a person can tell what it is doing (in teleoperation) or what it will do (when programming it).

Manipulator programming languages are a major topic of research in laboratories. There are at least a dozen languages now of some merit. Although this is too many to discuss in this report, we can list a few of the goals that their designers have been attempting to achieve.

* Ease of learning. Not everyone who has to use a robot is a skilled computer programmer.
* Ease of debugging. It should, for example, be possible to check out a new robot control program one step at a time to reduce the chance of an accident.
* Computing power. It should be easy to describe complex procedures that must frequently be performed. For example, an assembly robot should only have to be told where each part goes and it should be able to work out the required arm motions by itself. (Although much progress has been made, this is still a difficult research problem.)
* Extensibility. It should be easy to make the robot perform new actions, or tell it how to use a new sensor or tool.
* Low cost. The software available for programming the robot and the software that carries out that program should be able to run in a small, inexpensive computer.
* Parallelism. For efficiency, the language should allow programming for two or more robots working on different parts of a task at the same time.

No standards for manipulator programming languages have emerged as yet, and in fact researchers are still trying to determine what facilities should be included in such languages. In the next five years, there will be considerable research on using computer-aided design (CAD) systems to make it easier to specify tasks for a robot.

3.7.3. Generating Information

Computers can be used to present information in various modes including:

* Written Language
* Spoken Language
* Graphics
* Pictures

One of the principal concerns in artificial intelligence is developing methods for tailoring the presentation of information to individuals. The presentation should take into account the needs, language abilities, and knowledge of the subject area of the person or persons. In many cases, generation means deciding both what to present and how to present it. For example consider a repair advisor that leads a person through a repair task. For each step, the advisor must decide which information to give to the person. A very naive person may need considerable detail, a more sophisticated person would be bored by it. In deciding how to present information, there may, for example, be several ways of referring to a tool. If the person knows the tool's name then the name could be used, if not, it might be referred to as "the small red thing next to the toolchest". The decision may extend to other modes of output. For example, if a graphic display is available, a picture of the tool could be drawn rather than a verbal description given.

3.7.3.1. Current Status

At present, most of the generation work in artificial intelligence is concerned with generating language. Quite a few systems have been developed to produce grammatical English (and other natural language) sentences. However, although a wide range of constructions can be produced, in most cases the choice of which construction (e.g., active or passive voice) is made arbitrarily. A few systems can produce stilted paragraphs about a restricted subject area.

A few researchers have addressed the problems of generating graphical images to express information instead of language. However, many research issues remain in this area.

3.7.3.2. Research Issues

Some of the basic research issues associated with generating information include:

* Deciding which grammatical construction to use in a given situation.
* Deciding which words to use to convey a certain idea.
* Producing coherent bodies of text, paragraphs or more.
* Tailoring information to fit an individual's needs.

3.8. Reasoning

We have used the term "reasoning" to refer to the process of using information to make decisions, learn, plan, and carry out actions in the world.

There are many *roles for reasoning* including:

* Interpreting sensory information.
* Deciding what to output.
* Assimilating information.
* Recognizing (diagnosing) a situation, e.g., a medical problem, equipment failure, a failure of a robot to perform a task properly.
* Planning actions, e.g., assembly actions (for manipulators) navigation (path planning) battle strategy (not carried out by a system, but planned and told to a person).
* Monitoring the execution of plans and situations.

3.8.1. Assimilating Information

Being in any kind of changing environment and/or interacting with the environment means getting new information. That information must be incorporated into what is already known, tested against it, used to modify it, etc. Since one aspect of intelligence is the ability to cope

with a new and/or changing situation, any intelligent system must be able to assimilate new information about its environment.

Since it is impossible to have complete and consistent information about everything, the ability to assimilate new information also requires the ability to detect and deal with inconsistent and incomplete information.

3.8.1.1. Current Status

All artificial intelligence systems must assimilate information to some extent. One of the places the problem is addressed most directly is in multi-sensory integration, where information from multiple sensors is interpreted and combined in order to identify objects. Some techniques have been developed for integrating new information, but basic research issues remain, primarily related to the problems of combining inconsistent or uncertain information.

3.8.2. Expert Systems

'Expert systems' are computer programs that capture human expertise about a specialized subject area. Some example applications of expert systems are:

Medical Diagnosis
INTERNIST, MYCIN, PUFF

Mineral Exploration
PROSPECTOR

Diagnosis of Equipment Failure
DART

Information Integration

The basic technique behind expert systems is to encode an expert's knowledge as rules stating the likelihood of a hypothesis based on available evidence. The expert system uses these rules and the available evidence to form hypotheses. If evidence is lacking, the expert system will ask for it.

An example rule might be:

IF THE JEEP WILL NOT START
and
THE HORN WILL NOT WORK
and
THE LIGHTS ARE VERY DIM
then
THE BATTERY IS DEAD

with 90 PERCENT PROBABILITY

If an expert system has this rule and is told:

"THE JEEP WON'T START,"

the system will ask about the horn and lights and decide the likelihood that the battery is dead.

3.8.2.1. Current Status

Expert systems are being tested in the areas of medicine, molecular genetics, and mineral exploration, to name a few. Within certain limitations these systems appear to perform as well as human experts. There is at least one commercial product based on expert system technology.

Each expert system is custom-tailored to the subject area. It requires extensive interviewing of an expert, getting the expert's information into the computer, and verifying it, and sometimes writing new computer programs. There is extensive research required to improve the process of getting the human expert's knowledge into the computer and to design systems that do not require programming changes for each new subject area.

"In general, the following are prerequisites for the success of a knowledge-based expert system:

* There must be at least one human expert acknowledged to perform the task well.
* The primary source of the expert's exceptional performance must be special knowledge, judgment, and experience.
* The expert must be able to explain the special knowledge and experience and the methods used to apply them to particular problems.

* The task must have a well-bounded domain of application."*

3.8.2.2. Research Issues

Basic research issues in expert systems include:

* The use of causal models, i.e., models of how something works to help determine why it has failed.
* Techniques for reasoning with incomplete, uncertain, and possibly conflicting information.
* Techniques for getting the proper information into rules.
* General-purpose expert systems that can handle a range of similar problems, e.g., work with many different kinds of mechanical equipment.

3.8.3. Planning

Planning is concerned with developing computer systems that can combine sequences of actions for specific problems. Samples of planning problems include:

* Placing sensors in a hostile area.
* Repairing a jeep.
* Launching planes off a carrier.
* Combat operations.
* Navigation.
* Gathering Information.

Some planning research is directed towards developing methods for fully automatic planning, other research is on interactive planning, in which the decision making is shared by a combination of the person and the computer. The actions that are planned can be carried out by either people or robots or both.

An artificial intelligence planning system starts with:

* Knowledge about the initial situation: e.g., partially known terrain in hostile territory.

---

* Duda, R. O., J. G. Gaschnig, "Knowledge-Based Expert Systems Come of Age," BYTE Publications Inc., Fairchild Camera and Instrument Corp., Palo Alto, California, and SRI International, Menlo Park, California (September 1981).

* Facts about the world: e.g., moving changes location.
* Actions that can be done: walk, fly, look around, hide.
* Available objects: e.g., a platform on wheels, arms, sensors.
* A goal: e.g., installing sensors.

The system will produce (either by itself or with guidance from a person) a plan containing these actions and objects that will achieve the goal in this situation.

3.8.3.1. Current Status

Planning is still in the research stages. The research is both theoretical in developing better methods for expressing knowledge about the world and reasoning about it, and more experimental in building systems to demonstrate some of the techniques that have been developed. Most of the experimental systems have been tested on small problems. Recent work at SRI on interactive planning is one attempt to address larger problems by sharing the decision-making between the human and machine.

3.8.3.2. Research Issues

Research issues related to planning include:

* Reasoning about alternative actions that can be used to accomplish a goal or goals.
* Reasoning about actions in different situations.
* Representing spatial relationships and movements through space and reasoning about them.
* Evaluating alternative plans under varying circumstances.
* Planning and reasoning with uncertain, incomplete and/or inconsistent information.
* Reasoning about actions with strict time requirements. For example, some actions may have to be performed sequentially or in parallel or at specific times (e.g., night time).
* Replanning quickly and efficiently when the situation changes.

3.8.4. Monitoring Actions and Situations

Another aspect of reasoning is detecting that something significant has occurred (e.g., that an action has been performed or that a situation has changed). The key here is significant. Many things take place and are reported to a computer system; not all of them are significant all the time. In fact, the same events may be important to some people and not to others. The problem for an intelligent system is to decide when something is important.

We will consider three types of monitoring: monitoring the execution of planned actions, monitoring situations for change and recognizing plans.

3.8.4.1. Plan-Execution Monitoring

Associated with planning is execution monitoring, that is, following the execution of a plan and replanning (if possible) when problems arise, or possibly gathering more information when needed. A monitoring system will look for specific situations to be sure that they have been achieved. For example, it would determine if a piece of equipment had arrived at a location it had planned to be moved.

We characterize the basic problem as follows: given some new information about the execution of an action or the current situation, determine how that information relates to the plan and the expected situation, and then decide if that information signals a problem, and, if so, what options are available for fixing it. The basic steps are: (1) find the problem (if there is one), (2) decide what is affected, and (3) determine alternative ways to fix the problem. Methods for fixing a problem include: picking another action to achieve the same goal, trying to achieve some larger goal another way, or deciding to skip the step entirely.

Research in this area is still in the basic stages. At present, most approaches assume a person supplies new information about the situation (unsolicited). However, for many problems the system must be

able to acquire directly the information needed to be sure a plan is proceeding as expected, instead of relying on volunteered information. Planning to acquire information is a more difficult problem because it requires that the computer system have information about what situations are crucial to a plan's success and detect that those situations hold. Planning too many monitoring tasks could be burdensome, while planning too few might result in the failure to detect an unsuccessful execution of the plan.

3.8.4.2. Situation Monitoring

Situation monitoring entails monitoring reported information in order to detect changes, for example, to detect movement of headquarters or changes in supply routes.

Some research has been devoted to this area, and techniques have been developed for detecting certain types of changes. Procedures known by names such as "demons"* can be set to be triggered whenever a certain type of information is asserted into a database. However, there are still problems associated with specifying the conditions under which they should trigger. In general, it is quite difficult to specify what constitutes a change. For example, a change in supply route may not be signalled by a change of our truck's route, but in some cases three trucks could signal a change. A system should not alert a person every time a truck detours, but it should not wait until the entire supply line has changed. Specifying when the change is significant and developing methods for detecting it are still research issues.

3.8.5. Plan Recognition

Plan recognition is the process of recognizing another's plan from knowledge of the situation and observations of actions. The ability to recognize another's plan is particularly important in adversary situations where actions are planned based on assumptions about the

----

* Not to be confused with RAND'S DEMONS (semiautonomous ground vehicles).

other side's intentions. Plan recognition is also important in natural language generation because often a person will ask a question or make a statement as part of some larger task. For example, if a person is told to use a ratchet wrench for some task, the question "What's a ratchet wrench?" may be asking "How can I identify a ratchet wrench?" rather than "Give me a dictionary definition of a ratchet wrench?" Responding appropriately to the question entails recognizing that having the wrench is part of the person's plan to do the task.

Research in plan recognition is in early stages and requires further basic research, particularly on the problem of inferring goals and intentions.

4. ARMY APPLICATION CATEGORIES

The analysis described in Section 2 resulted in identification of 100 specific concepts for AI/robotic combat/combat-support systems. Considering variations or evolutionary forms of these systems, many hundreds of possibilities are implied. Although these concepts generally illustrate the possibilities, they are too fine-grained to serve as a guide for research plans. Therefore, the concepts were used as a basis for defining ten broad categories of applications.

The synthesis and definition of application categories is described in Section 4.1. In addition, to more clearly indicate the nature of the categories, SRI selected a single example of each category and developed a detailed design concept for that example. The examples are described in Section 4.2.

4.1. Application Categories

Application categories are groupings of the various application concepts derived in Section 2 that show similarity in the technological aspects of AI/robotics involved. Defining such appropriate categories was an iterative, judgmental process. The approach involved review of the concepts and consultation among research team members with extensive experience, both military and technical. Several factors were used as a guide in this process.

* Technological Similarity--Concepts in a group require advances in similar technical areas of AI/robotics.
* Military Use--Each category should pertain to a recognizable element of military activities.
* Comprehensiveness--The categories should encompass all potential combat/combat-support AI/robotics applications, as illustrated by the derived concepts.

The application concepts are not advanced as the specific concepts in each category that the Army should or would develop. The categories themselves, however, do represent areas in which development efforts are likely to produce worthwhile advances in Army capabilities, or other advantages such as personnel and cost savings.

4.1.1. Category Definitions

Ten categories of applications were defined and are discussed in the following subsections. The application concepts that are contained in each category are also listed. The ten categories are:

1. Human/Equipment Interface Aids
2. Planning and Monitoring Aids
3. Expert Advisors
4. Data Assimilation and Access Aids
5. Handling Support Systems
6. Support Systems
7. Situation Assessment Systems
8. System Controllers
9. Weapons
10. Information Collectors

4.1.1.1. Human/Equipment Interface Aids

These systems are intended to speed or otherwise facilitate the communications or physical interactions between soldiers and equipment. They would incorporate capabilities to interpret the meaning of human speech or actions. They may be selective in their transmission of information, highlighting important items and suppressing unnecessary detail.

The concepts included in this category are:

* Speech Command Auditory Display System
* Voice Helicopter Control System
* Scene Interpreter/Clarifier
* Multi-Lingual Order Generator
* Division Commander's Quick Data-Access System

4.1.1.2. Planning and Monitoring Aids

This category includes systems that would create a plan to accomplish specified goals, consistent with constraints. The systems could monitor plan execution and modify plans as changing circumstances dictated. They could generate instructions to implement plans. The systems could have varying degrees of human participation ranging from referral of all planning choices for human decision to total autonomy once goals were given.

The concepts included in this category are:

* Mission Execution Monitor
* Signal Array Planner
* Weapon Selection Planner
* Missile Launch Planner/Controller
* River Crossing Planner
* Covering Force Maneuver Planner
* ASP Layout Planner
* Brigade Mission Planning Aid
* Soldier's Movement Guide
* Nuclear Fire Planner

4.1.1.3. Expert Advisors

This category includes systems designed to give expert advice to humans, based on extensive stored knowledge of human experts in the fields concerned. Designed for interactive discourse with humans, they would provide guidance on further information needs that would help to

define the problem and its solution. They might also incorporate causal modeling. They would include the necessary hardware, interfaces, and communication links to make their services readily accessible.

The concepts included in this category are:

* Emergency Repair and Maintenance Advisor
* Missile-Launch Trouble Shooter
* Combat Vehicle Service and Survival Advisor
* EOD Advisor
* Water Finder

4.1.1.4. Data Assimilation and Access Aids

This category includes systems that would assimilate new information into distributed databases, and extract information in forms that would be pertinent to the users needs. They would integrate partial or conflicting information from multiple sources and maintain an updated "world model" as information was received. They would provide assistance to the database user in reaching appropriate forms of queries and would indicate gaps in knowledge where such gaps existed.

The concepts included in this category are:

* Interrogation Support System
* C^2 Database Query Language
* Route Planning Aid
* Combat Vehicle C^2
* Imagery Interpretation Aid
* Adaptive Database Reconfiguration System
* Multi-Sensor Data Assimilator

4.1.1.5. Handling Support Systems

This category includes items of equipment designed to support performance of specific combat/combat-support tasks of a handling or manipulative nature. The systems may be used in conjunction with other equipment, or mounted on such equipment. Systems would be generally

transportable but not independently mobile. They might incorporate some limited human controlled or pre-programmed movement in the immediate vicinity of task performance.

The concepts included in this category are:

* Artillery Loader
* Tank Ammunition Handler
* Tank Gun Loader
* Contaminated Clothing Handler
* Contaminated Casualty Handler
* Cargo Handler
* Refueler
* Vehicle Recovery Aid
* Multi-Purpose Manipulator
* Ammunition Handler
* Helicopter Missile/Rocket Reloader
* Nuclear Munition Outloader

4.1.1.6. Support Systems

This category includes systems designed to perform specific combat-support tasks involving some degree of autonomy in performance or mobility.

The concepts included in this category are:

* Vehicle Decontaminator
* Armor Resupply and Servicing Vehicle
* Line Charge Layer
* Semi-Autonomous Assault Raft
* Air Robotic Platform
* Ground Robotic Platform
* Combat Vehicle--Support Slave
* Combat Porter
* Mine Emplacer
* Soldier's Slave
* Engineer Reconnaissance Robot

* Remote Communications Relay
* Adaptive Airborne Communications Relay
* Smoke Layer
* Infantry Precursor
* Armor Precursor
* CP Antenna-Remoting System
* Man-Packed Portable Deception System
* EOD Assistant
* Airborne Minefield Detection System
* Barrier Emplacement Aid
* Remote Adaptive Jamming System
* Mine Clearer

4.1.1.7. Situation Assessment Systems

The systems in this category are designed to assimilate information, analyze it considering existing databases, and infer ranges of possible meaning of the available data (which may be incomplete or contradictory). The systems could infer enemy capabilities, realistic options and likely plans. They might also identify important knowledge gaps and further information needs.

The concepts included in this category are:

* Brigade Situation Analyzer
* Artillery Movement Assessment System
* Tactical Threat Projection System
* Super Sextant
* Chemical Hazard Warning/Analyzer
* Deception Identification System

4.1.1.8. System Controllers

This category comprises devices that would generate instructions (mechanical, electrical, or audio) to control other systems, based on continuous information input. They include varying degrees of human participation in the control decisions involved. They generally have

capabilities for situation assessment, planning, and monitoring execution.

The concepts included in this category are:

* Line-of-Sight Controller
* Safe Return Controller
* Fire Allocation and Control Systems
* IFF Module
* Copilot
* Armor Hit-Avoidance System
* Helicopter Automatic-Target-Acquisition System
* EW Equipment Controller
* Communication Network Manager
* Adaptive EW Control System
* Target Acquisition and Homing Device
* Target Acquisition/Allocation System

4.1.1.9. Weapons

Designed to inflict damage on enemy personnel or equipment, the devices in this category incorporate varying degrees of target acquisition, identification, and homing capabilities. They possess the capability to seek out and destroy targets consistent with broad guidance from their users.

The concepts included in this category are:

* TEARS/DEMONS
* Light Fighting Sentry
* Heavy Fighting Sentry
* Close Air-Defense Sentry
* Infantry Robotic Grenade
* Homing Tank/Killer

4.1.1.10. Information Collectors

Applications concepts in this category would collect information about the friendly or enemy situation or terrain. The devices would be capable of making internal decisions within bounds on what to collect and how to go about it. In general, systems would possess some degree of autonomous air or ground mobility.

The concepts included in this category are:

* River Reconnaissance System
* NBC Reconnaissance Robot
* Aerial Observer/Designator
* Ground Observer/Designator
* Remote Scene Analyzer
* EW Sentry
* NBC Sentry
* Wire Tapper
* Street Walker Scout
* Approach Sentry
* Leach Armor Marker
* Multi-Purpose Sensor Emplacer
* Tactical Reconnaissance Robot
* Soldier's Auxiliary Eye

4.1.2. Systems and Technology Relationships

The ten application categories are interrelated and fit differently into the normal Army approach to fielding systems. These relationships are depicted in Figure 3.

The nature of five of the categories is such that they generally contain specific end items or distinct components of end items of Army equipment (Weapons, Support Systems, Information Collectors, Handling Support Systems, System Controllers). Development efforts on the other five categories (Human/Equipment Interface Aids, Planning and Monitoring Aids, Expert Advisors, Data Assimilation and Access Aids, Situation

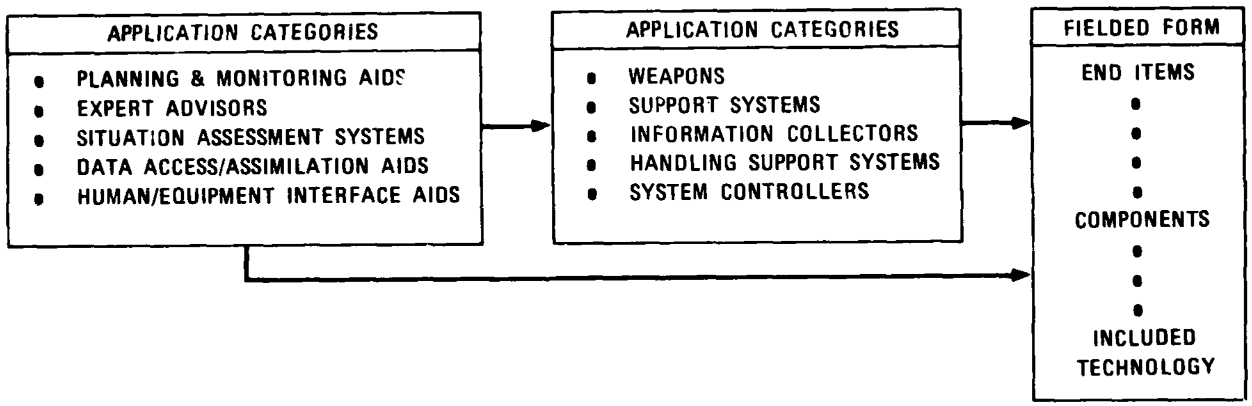


FIGURE 3 AI/ROBOTICS SYSTEM INTEGRATION

Assessment Systems) are more likely to lead to components or technology which would be included in Army systems. As illustrated in the figure, developments in the latter five categories are needed as an ingredient of the first five categories.

Development of useful applications in the ten categories will require advances in the various AI/robotics technology areas that are assessed in Section 3. Figure 4 shows which of the supporting technology areas are significantly involved in which application categories.

It is important to observe that the matrix in Figure 4 is quite dense--in the sense that each application category depends on many technology areas. The implication for research planning is that work in all technology areas is needed to achieve truly effective applications. (Of course, some prioritization and acceptance of less than optimum capabilities in the application end items will be necessary.)

Another important observation from Figure 4 is that effective applications in most categories depend on advances in both AI and robotics. An integrated approach to planning research in these areas (i.e., AI/robotics research) is important for achieving many useful capabilities.

4.2. Category Examples

As an aid to understanding the application categories and the technology involved, SRI chose, from each category, one of the application concepts derived in Section 2 as an example system for more detailed examination. For each example, a conceptual design was developed and the technology gaps affecting achievement of the designs were identified. The examples selected for each category are shown in Table 19.

Table 19

CATEGORY EXAMPLES

Category	Example
1. Human/Equipment Interface Aids	1. Division Commander's Quick Data-Access System
2. Planning and Monitoring Aids	2. Brigade Mission Planning Aid
3. Expert Advisors	3. Emergency Repair and Maintenance Advisor
4. Data Assimilation and Access Aids	4. Interrogation Support System
5. Handling Support Systems	5. Tank Ammunition Handler
6. Support Systems	6. Mine Clearer
7. Situation Assessment Systems	7. Tactical Threat Projection System
8. System Controllers	8. Safe Return Controller
9. Weapons	9. Light Fighting Sentry
10. Information Collectors	10. River Reconnaissance System

The ten examples are described in detail in Section 4.2.1 through 4.2.10. The conceptual design efforts on the separate examples identified many components that would be needed in more than one example. These common components are described in Section 4.2.11.

The primary consideration in selecting these examples was to represent the AI/robotics technology involved in the category concerned. The choices should not be interpreted as anything else. They are not necessarily the concept that appears most feasible--in fact, examples of a long-range nature were favored in order to examine medium-to-long-range research and development implications. They are not necessarily the most potentially useful to the Army within the category.

Finally, their selection as illustrations should not be construed as a recommendation that the Army initiate or pursue development of the item. Among these examples, and the other concepts described in Appendix A, there are undoubtedly many ideas worthy of further evaluation. However, such evaluations were beyond the scope of this effort. The examples will have served their purposes if they aid in understanding the categories and the technological needs for achieving eventual fielded applications in those categories.

TECHNOLOGY AREAS	HUMAN/EQUIPMENT INTERFACE AIDS	PLANNING & MONITORING AIDS	EXPERT ADVISORS	DATA ASSIMILATION AND ACCESS AIDS	HANDLING SUPPORT SYSTEMS	SUPPORT SYSTEMS	SITUATION ASSESSMENT SYSTEMS	SYSTEM CONTROLLERS	WEAPONS	INFORMATION COLLECTORS
SENSORS	●				●	●		●	●	●
EFFECTORS	●				●	●		●	●	●
MANIPULATION	●				●	●			●	●
MOBILITY					●	●			●	●
LANGUAGE GENERATION	●	●	●	●			●	●		●
COMPUTATIONAL VISION	●				●	●	●		●	●
LANGUAGE INTERPRETATION	●	●	●	●	●	●	●	●	●	●
INFORMATION ASSIMILATION	●	●	●	●			●	●		●
EXPERT SYSTEMS		●	●				●	●		●
PLAN RECOGNITION			●				●			
ACTION PLANNING		●	●		●	●	●	●	●	●
SITUATION MONITORING		●			●	●	●	●	●	●

(APPLICATION CATEGORIES heads the ten category columns.)

FIGURE 4 APPLICATION CATEGORY—TECHNOLOGY RELATIONS

4.2.1. Division Commander's Quick Data-Access System

4.2.1.1. Description

The Division Commander's Quick Data-Access System (QDAS) would be a briefcase-sized device intended for personal use of division commanders to quickly obtain information on the status of available resources and limited other situation information from data bases. It would include voice and graphic interfaces. It could be connected to data lines to provide complete access to available division automated databases, or it could retain key resource information for limited operation in an isolated mode.

4.2.1.2. Needs

The process of planning combat operations at division level involves staff study of information concerning the friendly and enemy situation, the terrain, the weather, and many other factors. The amount of data is voluminous and subject to rapid change. In order to focus staff attention and speed planning, commanders must narrow the possibilities of interest and issue appropriate guidance to the staff. Although some aspects of this process are interactive with the staff, other portions are highly personal, and can be greatly speeded and assisted by providing the commander quick access to data without recourse to his staff. In addition, in many situations the commander may have to make rapid decisions when staff resources are not available.

For example, if the commander has the ability to react to sudden changes in the weather, even while on the move, he may possess the key to winning the battle. Rapid consultation of resource data is essential to take advantage of opportunities or compensate for unexpected difficulties. Of course, there are many other changes that occur on the battlefield during the course of a battle. The commander who can react to such changes rapidly is in a superior position.

4.2.1.3. Employment Concept

The commander would employ QDAS whenever he wished to rapidly obtain key resource/situation information to aid his personal thought and planning processes. For example, it might be used prior to issue of planning guidance to the staff, or in reacting to unexpected developments in an operation when staff assistance was not readily available.

At the division, the QDAS would normally be connected to the division databases by data lines. It might be loaded with selected information from these databases, disconnected and transported with the commander to provide a limited capability when he was away from his headquarters.

The system would respond to voice queries and would provide requested data in voice or graphic form. It would interact with the commander and would assist him in getting the particular data he wanted.

4.2.1.4. Capabilities

At the division CP, the Commander's Quick Data-Access System would provide the commander with a real-time ability to query available resource and situation databases. The system would respond to his voice-spoken questions and provide the requested data, if it was available, in a combination of voice and graphic display.

The system, upon voice command, could display such items as ammunition and POL status, unit strength status, major equipment item status, casualties, and current unit deployments.

When disconnected from the division CP data links, it should retain current resource status and limited situation data in its memory. It should operate for a period of up to one hour on its self-contained power supply.

4.2.1.5. Organization Distribution

The QDAS would be issued on the basis of one per division commander. Officers would be trained in its use as part of their command and staff-level schooling.

4.2.1.6. Physical Design

The QDAS would be a briefcase-sized device incorporating the following principal hardware:

* A computer
* A word recognizer
* A speech synthesizer
* A graphics terminal.

4.2.1.7. Logical Design

This design, a reasonably short-term system with limited capabilities, would build on existing technology for recognizing words spoken in isolation. (A longer-term general-purpose speech understanding system might be designed differently and would require much more basic research.)

Figure 5 illustrates the components of the QDAS.

4.2.1.7.1. Word Recognizer

For relatively early fielding, an existing system for recognizing isolated words could be used for this component. The word recognizer's limitations, such as requirements for training by each user, ability to recognize only isolated words, and restrictions on vocabulary size will be the major limitations of the division commander's quick data-access system. As the capabilities of word-recognition systems improve, these limitations will become less severe.

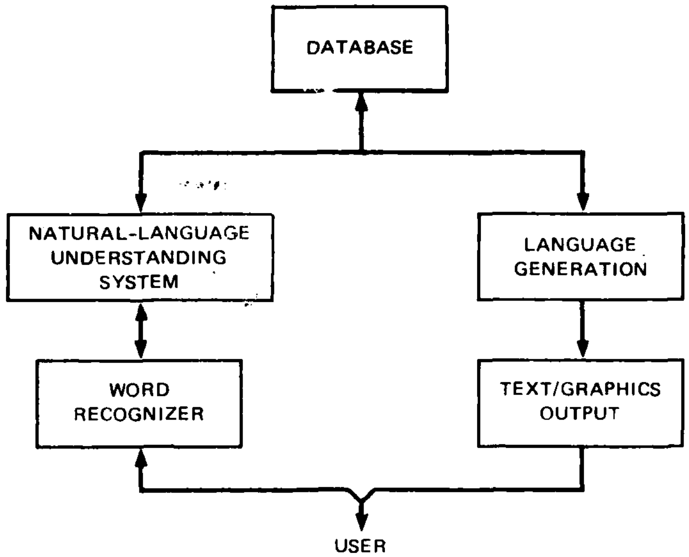


FIGURE 5 LOGICAL DESIGN OF THE DIVISION COMMANDER'S QUICK DATA-ACCESS

4.2.1.7.2. Natural Language Understanding System

The component that interprets the spoken words and poses queries to the database system can build on existing techniques for English access to database. However, modifications will be required to handle the uncertainties of the spoken input, and the differences in grammar.

Either the vocabulary would have to be limited to correspond to the limitations of the word-recognition system, or new techniques will be required to extend the capabilities of the word recognizer.

The natural language system should be one that is independent of the form or subject area of the database and it should provide easy adaptability to new databases and subject areas.

4.2.1.7.3. Text and Graphics Output

Existing techniques for generating written and spoken text from responses to database queries could be used. New methods should be

devised to present the information more effectively as a mixture of text and graphics, when that was appropriate.

4.2.1.8. Technology Gaps

The major gaps in the technology are:

Language Interpretation

* Interpreting extended dialogs and text where meaning depends on the context
* Interpreting language that is "ungrammatical", e.g., slang or dialect
* Interpreting uncertain input (e.g., speech)
* Recognizing continuous speech

Language Generation

* Tailoring information to fit an individual's needs
* Deciding what words and grammatical constructs to use Participating in a dialog--when the information is stored as "words" e.g., database, when information is stored as maps, charts, etc.

Information Assimilation

* Combining information from multiple databases

Supporting Technologies

* Voice input with high level noise background
* Semiconductor circuits such as VHSIC

4.2.1.9. Evolutionary Versions

Longer-range versions of this device would be capable of interpreting continuous speech.

4.2.2. Brigade Mission Planning Aid

4.2.2.1. Description

The purpose of the Brigade Mission Planning Aid is to provide rapid mission planning and operations assistance to the Brigade Commander and his key staff members in the decision/planning/execution process during the course of a dynamic battlefield situation. The system would be designed as a self-contained (except power supply), transportable module, suitable for mounting in an APC or fixed facility when available.

4.2.2.2. Needs

A continuing requirement exists on the extended battlefield for the commander to have a rapid, responsive planning capability to enhance C^2 and aid the command group in analyzing, planning, and acting more quickly than a numerically superior enemy force. The Brigade Mission Planning Aid would give the commander the capacity to rapidly plan decisive maneuvers further into the future. It would increase planning flexibility, and aid the brigade in seizing and maintaining the initiative at the earliest opportunity. The most efficient allocation of all available firepower, maneuver, and target acquisition would be facilitated by the use of a system such as the Brigade Mission Planning Aid.

4.2.2.3. Employment Concept

The system would be used iteratively by the commander and key staff members to aid them in planning. Based on all available data pertinent to a particular mission, the mission planning aid would provide timely information regarding the best options possible to carry out a mission. This would entail an impact analysis to include the selection of, or recommendations on employment of subordinate units, time phasing, routes and alternates, plan formulation, impact on logistics, projected casualties, and an estimate of successful outcome.

The planning aid would, in addition, postulate the possible follow-up actions that the commander could consider in the case of success or

failure of alternatives, such as exploitation or pursuit options. The mission planner would be interactive and able to adjust to a rapidly changing combat situation. It would monitor the situation as it developed based on a continuing input by operators, and analyze the impact as facts become available.

The Brigade Mission Planning Aid would also be able to compare the particular mission to previous missions of the same type, and for that brigade, select options and alternatives. It would be designed to assist in fitting the forces to the ground mission as the battle developed and also assist in the decisions that enable the commander to coordinate the concentration of firepower, and consider the weather and terrain.

The Brigade Mission Planning Aid would be employed at Brigade HQ/CP, on a continuous basis.

4.2.2.4. Capabilities

The Brigade Mission Planning Aid should be able to assimilate data by keyboard or voice entry. As the battlefield situation developed and critical points were reached, that new data would be input as it became available and the planning aid would analyze the ramifications, if any, and provide further options. An operator should be able to query the planning aid regarding, for example, recommended deployment, combat support requirements and fire and maneuver considerations, objective status, etc. The results of a mission plan and status query should be available in hard copy. The system should be able to operate either on the power of a transporting APC or normal fixed power system.

4.2.2.5. Organizational Distribution

The Brigade Mission Planning Aid would be an item of TOE equipment in all divisions, issued on the basis of one per brigade headquarters. Two operators and one alternate would be trained as part of their regular duties, with one operator being designated as primary. Maintenance would be performed within the normal organizational structure relating to specialized computer equipment of this nature.

4.2.2.6. Physical Design

The Brigade Mission Planning Aid would be a transportable file-cabinet-sized device with:

* A central computer
* A removable mass storage device
* A video display and keyboard
* Voice input and output devices
* A communications link to databases at division headquarters
* A small terminal that can be used at a distance from the main system.

The device would be completely self-contained, with the exception of reliance on an external power source (vehicle or normal commercial power).

4.2.2.7. Logical Design

The primary components of the Brigade Mission Planning Aid would be a planning system and a plan-execution monitoring system. The other major components would be an interface to relevant databases and good user interface. Figure 6 shows the system's logical components.

4.2.2.7.1. Planning and Monitoring System

The general requirements of the planning and plan-execution monitoring systems are described in Section 4.2.11. For this application, the actions would be those that the brigade commander plans, (e.g., troop movement, supply movement, use of firepower). As information about the operation is received and recorded in the database, the monitoring system would follow the plan's execution and alert the commander if a planned action did not succeed. In such cases, the planner would be used to determine alternative actions that could be performed in the new circumstances.

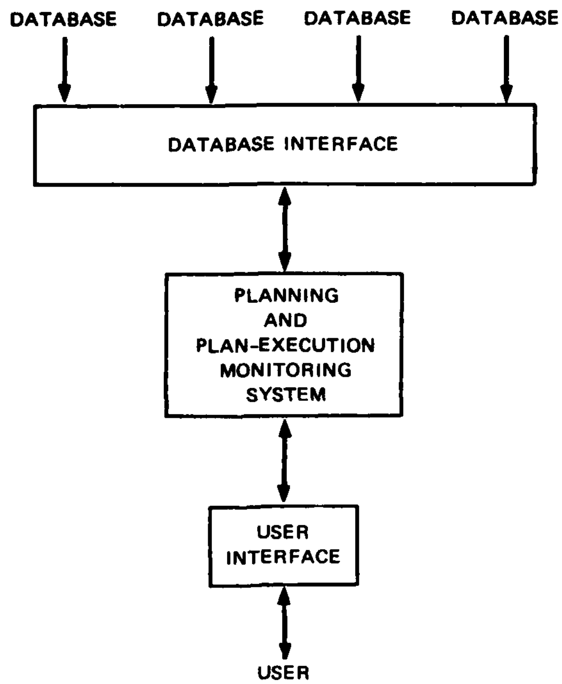


FIGURE 6 LOGICAL DESIGN OF THE BRIGADE MISSION PLANNING AID

4.2.2.7.2. Databases and Database Interface

The databases used by the planner should have the following contents:

* Troops: status, strength, location.
* Supplies: location, amounts, information to help estimate time to distribute items wherever needed.
* Equipment: status (who is using, is it working?), location.
* Environment: weather, terrain, hostile factors (mines, contaminants, etc).
* Enemy status: troop & equipment strength and location, projected actions.
* Historical information: previous operations and the actions taken and their outcomes.

To the extent available, some of these data would be input and updated from division databases by way of a link. Other elements would be entered manually by the operator.

The form of the databases is not crucial to the design at this stage. The databases should also be available for other purposes, (e.g., threat projection), and consequently they should be designed for maximum accessibility and flexibility (and hopefully with the requirements of systems such as this in mind). For this system, the main consideration would be to provide a means of getting the data into the database. Another important consideration would be to provide an interface to the databases so they could be used in planning.

The databases must be able to assimilate new information, and to handle incomplete and possibly conflicting information. If the databases contain overlapping information, the interface must be able to coordinate the information from the different databases. This is an important area of research in database management as well as artificial intelligence.

4.2.2.7.3. User Interface

The user interface should incorporate many of the mixed-media features described in Section 4.2.11. As a minimum, there should be text and graphic interfaces. At least one high-resolution color display should be used to display maps, overlayed with graphical depictions of troop, equipment, and supply locations, and to display graphic representation of the plans. Input should be by voice, typing, and by pointing to items shown on the display.

4.2.2.8. Technology Gaps

Many of the technology gaps in the Brigade Mission Planning Aid are discussed in Section 4.2.11 in the discussions of planning, plan-execution monitoring, and interfaces to the user. The gaps in the technology include:

Action Planning

* Reasoning about alternative actions
* Reasoning about actions in different situations
* Reasoning about actions with strict time requirements
* Evaluating alternative plans under varying circumstances
* Comparing current plans with historical information
* Reasoning fast and efficiently when the situation changes

Situation Monitoring

* Plan-execution monitoring
* Detecting that goals have been accomplished based on reported actions
* Detecting that a planned action has not been successfully executed
* Real-time interaction between planning and monitoring

Information Assimilation

* Combining information from multiple databases

Language Interpretation

* Interpreting extended dialogs and text where meaning depends on the context
* Interpreting language that is "ungrammatical", e.g., slang or dialect
* Interpreting uncertain input (e.g., speech)
* Recognizing continuous speech

Language Generation

* Tailoring information to fit an individual's needs
* Deciding what words and grammatical constructs to use
* Participating in a dialog--when the information is stored as "words" e.g., database, when information is stored as maps, charts, etc.
* Constructing together coherent bodies of text (paragraphs or more)
* Presenting an appropriate mix of graphic and verbal information

Supporting Technologies

* Semiconductor circuits such as VHSIC

4.2.2.9. Evolutionary Versions

A preliminary version of this system could be a simple database access system. This could evolve to a version that suggests alternatives, without evaluating them.

4.2.3. Emergency Repair and Maintenance Advisor

4.2.3.1. Description

The Emergency Repair and Maintenance Advisor (ERMA) would be a small module to be used by combat or combat-support vehicle crewmen to obtain expert advice on possible ways to repair their equipment in emergency situations. It would be a self-contained hand-held unit, incorporating a microprocessor, input/output, and an expert system covering repair possibilities.

4.2.3.2. Needs

The growing complexity of Army equipment makes it more and more difficult for the soldier to devise and implement means to keep the equipment operating in situations where maintenance support is not available. In cases where damage renders the equipment useless, without destroying it, normal or unusual on-the-spot procedures may be able to temporarily restore some or all of the equipment's functions. ERMA is intended to increase the capabilities of the crew to devise and execute such procedures.

As battlefield operations move toward the air-land battle 2000 concepts, units will become more and more isolated from maintenance and repair support, enhancing the need for resourcefulness in keeping equipment operating. In addition, the requirements of continuous combat will enhance the need for prompt independent repair activities to maintain momentum despite minor equipment failures or damage.

4.2.3.3. Employment Concept

The ERMA would be used in emergency situations when repair beyond the normal operator maintenance level is urgently needed and cannot be obtained from normal maintenance channels. Repair may be needed as a consequence of system failure or combat damage. Vehicle operators or crew members would use it to try to diagnose the problem and determine whether or not some solution that could restore the vehicle to action were possible, using immediately available resources. If the dialogue were successful in reaching a diagnosis and possible course of action for repair, the system would then instruct the operator in a step-by-step temporary repair procedure. The ERMA would be issued and carried as an item of on-vehicle materiel (OVM) with the vehicle it pertains to. The same hardware module may be loaded with different software pertaining to different vehicles. When a vehicle was disabled, and the operator recognized that restoring it to action was beyond his knowledge, he would resort to ERMA for advice.

If vehicle battery power were available, the operator would connect the ERMA to the battery. If not, it would be capable of operating for a limited period on its own internal power supply. The operator would engage in a dialogue with ERMA, using either voice, keyboard, or graphic input, and would receive graphic and voice output. The dialogue would include prompting and questioning from ERMA to obtain data on the nature of the problem, and whether or not the operator could obtain useful resources (for example, a piece of conducting wire).

In its memory, the ERMA would retain a record of the diagnosis and of what actions were taken; this record could be reviewed by DS or GS maintenance personnel when it was possible to obtain their assistance with more permanent repairs.

4.2.3.4. Capabilities

The ERMA should be capable of providing advice equivalent to the Army's best trained and most experienced maintenance personnel. It should operate for one hour on its internal backup power, or

indefinitely on standard vehicle power. It should be rapidly loaded with software for different vehicles employing a separate program change unit (PCU). Programs themselves would be provided in the form of preloaded read-only-memory units for use in the PCU. Their structure would be such that they could be modified to accommodate vehicle modifications or improved knowledge on vehicle repairs. The programs would be regularly updated to reflect such changes.

4.2.3.5. Organizational Distribution

The ERMA would be issued on the basis of one per combat or combat support vehicle in all divisions and corps artillery battalions. PCUs would be issued on the basis of four per division. Expert programs would be supplied through maintenance supply channels.

The ERMA and PCU would be maintained within the normal division structure.

4.2.3.6. Physical Design

ERMA would be a small briefcase-sized device with the following hardware:

* A small computer with replaceable mass-storage
* A small terminal with a keyboard and display
* Voice input device
* Voice output device.

4.2.3.7. Logical Design

The Emergency Repair and Maintenance Advisor would primarily contain an expert system and a repair advisor. The expert system would encode diagnostic rules plus a model of how the system worked to help with cases rules did not cover. Input to the system would be from the operator. Figure 7 indicates the logical components of the system.

The expert system and repair advisor would be the same for all equipment. However, each item of equipment (e.g., M60A3 tank, M113

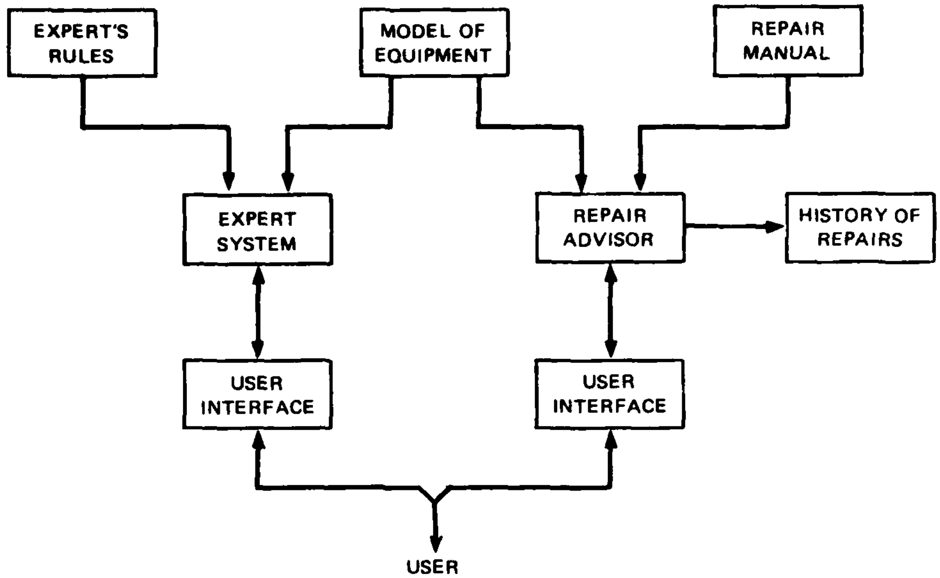


FIGURE 7 LOGICAL DESIGN OF THE EMERGENCY REPAIR ADVISOR

model, and repair manual, although many elements would be the same among them. The parts that differed with each class would reside on a removable ROM or other form of mass storage, so they could be transferred from one unit to another and updated with changes to the equipment.

4.2.3.7.1. Expert System

An expert system, as discussed in Section 4.2.11 would be used in this system. It should be an extension of expert system technology in order to be able to easily handle more than one type of equipment and to make effective use of a physical/electrical model of how the equipment worked. With such a model, deductions could be made about possible problems when failures occurred. This information might also be used to modify the rules to reflect local equipment modifications.

4.2.3.7.2. Repair Manual

The repair manual would be an on-line manual that could be indexed by the failures that had been detected by the expert system. Using videodisk or other technology, it could contain still and moving pictures of the equipment as well as written information.

4.2.3.7.3. Repair Advisor

The repair advisor would use the information in the repair manual and the model of the equipment to advise the person on how to perform the repair. The completion of each step would be reported as it was performed. Periodically, the advisor might ask for additional confirmation that the steps were being performed as indicated.

Simple repairs could be prestored sequences of steps. However, more complex repairs or unusual situations would require some planning by the repair advisor. A planning system that used the information in the manual augmented with descriptions of general repair actions would be incorporated and used to plan some nonstandard repairs.

The advisor would record equipment failures and repairs undertaken for future reference.

4.2.3.7.4. User Interfaces

The ERMA should be able to tailor its presentation of information to the using individual so that it would provide information in the most suitable form.

A small display would be available to provide pictures or diagrams of appropriate parts, and voice input and output would be available to free the person's hands and enable him to interact while performing repairs.

4.2.3.8. Technology Gaps

In addition to the gaps existing in the basic planning, expert system, and interface components, the following gaps currently exist in the other technologies:

Expert Systems

* Getting the proper information into rules
* Methods for easily changing rules
* Representing basic repair actions for use by the repair advisor
* Encoding information in the repair manual so it can be used by the repair advisor
* Using causal models in diagnosis
* Reasoning with incomplete, uncertain, and possibly conflicting information
* Developing general-purpose expert systems that can handle a range of similar problems

Information Assimilation

* Combining information from multiple databases
* Determining what information to acquire to help establish the certainty of information
* Combining and reasoning with incomplete and inconsistent information

Language Interpretation

* Interpreting extended dialogs and text where meaning depends on the context
* Interpreting indirect or subtle utterances, such as recognizing that "Can you reach the salt" may be a request to pass it
* Interpreting language that is "ungrammatical", e.g., slang or dialect
* Interpreting uncertain input (e.g., speech)
* Recognizing continuous speech

Language Generation

* Tailoring information to fit an individual's needs
* Deciding what words and grammatical constructs to use
* Participating in a dialog--when the information is stored as "words" e.g., database, when information is stored as maps, charts, etc.
* Presenting an appropriate mix of graphic and verbal information

Supporting Technologies

* Voice input with high level noise background
* Semiconductor circuits such as VHSIC

4.2.3.9. Evolutionary Versions

In the nearer term, the system could be limited to diagnosis and providing a smart index to a repair manual.

4.2.4. Interrogation Support System

4.2.4.1. Description

Intelligence units are tasked with an interrogation mission whose success is largely dependent on the timeliness and accuracy of response information. The Interrogation Support System (ISS), would be a portable device designed to provide the trained human interrogator with a tool to assist in and facilitate the rapid and thorough forward exploitation of POW/detainees for essential elements of information (EEI).

4.2.4.2. Employment Concept

Prior to employment, the ISS would be updated with appropriate intelligence information by a combination of automated input from divisional databases and manual entry of information such as EEI, and knowledge of the interrogation subject by the interrogator. At the interrogation site, the system would be used interactively by the interrogator, either in the presence of the subject or in isolation. Use could be effectively integrated with other techniques in the interrogation process to aid in producing desired psychological impacts on the subject.

The ISS would contain the EEI related to a particular interrogation and have the capability to detect inaccuracies in responses, lies, and a true response in satisfaction of those EEI. The module would be able to update and integrate the EEI as more, new, or conflicting data was input by the interrogator.

4.2.4.3. Needs

Efforts by the interrogator to meet requirements for efficient, rapid, and accurate forward exploitation of interrogation opportunities to satisfy EEI could be greatly aided by the employment of the Interrogation Support System. This system could aid in the determination of the validity of all detainee responses and, thereby, assist in the assessment of the potential value to intelligence of the information obtained. Further, it would aid in assessing the need for more prolonged detainee questioning for exploitation purposes. The human interrogator would be greatly assisted by having information gaps for a particular mission filled in by the ISS, as well as having responses integrated with other intelligence information so that variables such as conflicting, misleading data could be rapidly resolved.

4.2.4.4. Capabilities

The ISS would have the basic capability of assessing interrogation responses for pertinence and accuracy. In addition, it would have the capability of formulating questions and recommending questions based on deduction and inference from the information it knows and the information it receives.

4.2.4.5. Organizational Distribution

The Interrogation Support System would be a TOE item in the Division 86 CEWI Battalion, issued on the basis of one per CEWI Battalion. All interrogators would be trained in its use as part of their school training. It would be maintained in normal division maintenance channels.

4.2.4.6. Physical Design

The Interrogator would be a small, portable device, incorporating the following hardware:

* A computer
* Removable mass storage
* Keyboard and display
* Simple speech input and output devices.

4.2.4.7. Logical Design

The basis of this system would be a component that could correlate new information with existing information and perform the following functions:

(1) Determine if the new information conflicts with current information.

(2) Integrate any useful new information into the existing databases.

(3) Determine what further information might be of value and request it.

This system could be viewed as a special case of information integration. The key difference is that for the Interrogator, the newly-acquired information would not be assumed to be reliable and one of the purposes would be to ascertain its reliability. Many of the techniques used in other information integration problems would be applicable here; development of others would be required.

Figure 8 illustrates the logical design components of the interrogator.

4.2.4.7.1. Conflict Detection

The portion of the system that would detect conflicts would use methods for reasoning with uncertain and incomplete information to determine if the newly-acquired information appeared accurate. Since, in this system, the new information would not be assumed reliable, existing methods might require some revision or extension.

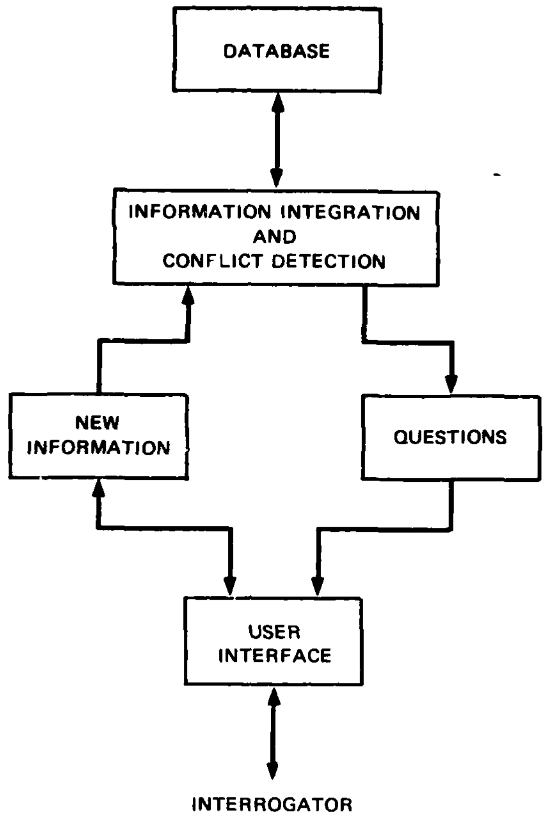


FIGURE 8 LOGICAL DESIGN OF THE INTERROGATOR

4.2.4.7.2. Information Integration

If the information were judged reliable, the same information integration techniques that have been described elsewhere could be used to update the database.

4.2.4.7.3. Posing New Questions

Deciding what further information was required, and what questions to ask would be somewhat similar to the information-gathering problem described for the River Reconnaissance System. The development of techniques for doing this is still a basic research issue in artificial intelligence.

4.2.4.7.4. User Interface

The system should be able to interact with the interrogator in English. The interaction could be either written or spoken. A graphic display for use of maps and diagrams should also be provided.

4.2.4.8. Technology Gaps

In addition to the technology gaps in interfaces, the following areas require further research:

Language Generation

* Tailoring information to fit an individual's needs
* Deciding what words and grammatical constructs to use
* Participating in a dialog--when the information is stored as "words" e.g., database, when information is stored as maps, charts, etc.

Language Interpretation

* Interpreting extended dialogs and text where meaning depends on the context
* Interpreting indirect or subtle utterances, such as recognizing that "*Can you reach the salt*" *may be a request* to pass it
* Interpreting language that is "ungrammatical", e.g., slang or dialect
* Interpreting uncertain input (e.g., speech)
* Recognizing continuous speech

Information Assimilation

* Combining information from multiple databases
* Determining that information is lacking
* Determining what information to acquire to help establish the certainty of information
* Combining and reasoning with incomplete and inconsistent information

Situation Monitoring

* Recognizing if the information obtained has achieved the desired goal

Supporting Technologies

* Voice input with high level noise background
* Semiconductor circuits such as VHSIC

4.2.4.9. Evolutionary Stages

A nearer-term version could be limited to the capability of detecting conflicts between responses and a database.

4.2.5. Tank Ammunition Handler

4.2.5.1. Description

The Tank Ammunition Handler would be a robotic device mounted on platforms used to carry tank ammunition. A 2-1/2 ton truck was chosen for this design. The device would be composed of three robotic arms, which work in conjunction to perform all actions to remove ammunition from pallets and hand it to a crewman inside the tank for final storage in racks. It would perform the operation of cutting bands, opening cannisters, removing the rounds and lifting/moving them to a position from which a single crew member can handle the final aspect of storage.

4.2.5.2. Needs

Rapid load out of Army units from peacetime bases is a critical aspect of readiness. This is particularly true in Europe, where units have great difficulty in meeting the tight time limits for clearing their bases. In a combat situation, rapid rearming of tanks is important to maintain momentum and to make the most use of critical tank resources.

The present manual system for rearming a tank is time consuming and labor intensive. A tank crew can be expected to take 3-to-4 hours to complete rearming. All four crew members must work intensively to accomplish the task. The Tank Ammunition Handler substitutes a robotic device for troop labor. In addition, the device can reload at the speed of the crew member placing the rounds in the ammunition racks.

As visualized in this design concept, the Tank Ammunition Handler could reduce the rearming time to approximately one hour.

4.2.5.3. Employment Concept

The Tank Ammunition Handler would perform the ammunition preparation and handling functions in the rear or well forward in the battle area. In rear areas, it may be employed to speed the outloading of armor units from their peacetime bases, thus aiding in meeting the critical time requirements for load out and movement to assembly areas. In forward areas, it may be used to service armor units between engagements, handling complete or partial reloads as time and resources permit.

In reloading operations, the Tank Ammunition Handler would be positioned near the tank and the ammunition supply, which may be on pallets or loose, on ammunition carriers or on the ground. Once positioned, the device would be controlled completely by a single crew member, inside the tank, allowing other crew members to perform other critical tasks such as maintenance or to rest. The crew member (loader) would instruct the device on the type and sequence of rounds to be furnished to him and on the route to be used by the device to pass the round to him through the tanks complex interior arrangement.

When instructed, the device would secure a round, prepare it, remove it, and hand it to the loader. If desired, it would take a spent cartridge from the loader and discard it outside the tank.

4.2.5.4. Capabilities

The Tank Ammunition Handler should be able to deliver one round per minute. It would perform all labor intensive functions of removal from pallets and cannisters and moving the round which are presently performed by the tank crew. The device could be completely controlled by the loader inside the tank. It would be designed to avoid transmitting any NBC contamination that might remain on cannisters to the rounds and subsequently into the tank.

4.2.5.5. Organizational Distribution

The Tank Ammunition Handler would be issued to armor battalions on the basis of one for each ammunition carrier. It would be maintained in normal division maintenance channels.

4.2.5.6. Physical Design

Figure 9 shows a design concept. It would be able to reload a tank from a pallet of cannistered rounds on the ground, but it could also take rounds from the conveyor of the Army's proposed Armored Supply Vehicle. The system could operate even in the presence of NBC contamination on the ammunition cannisters, without exposing the crew or tank interior to contamination. It could remove spent cartridges or dud rounds from the tank interior.

The system would include three different robot arms mounted on the bed of a 2-1/2 ton truck. All three arms would operate simultaneously in a coordinated way to speed the loading process. The arms would perform these three tasks:

(1) Taking the cannisters from the pallet -- the "depalletizing" arm.

(2) Lifting the cannisters to the hatch -- the "loading" arm.

(3) Handing the rounds inside the tank -- the "high-flexibility" arm.

The depalletizing and loading arms would be mounted permanently on a rectangular steel frame that fits within the bed of any 2-1/2 ton truck. The frame would also have a rack that would carry the high-flexibility arm. As the first step of the rearming process, the loading arm would lift the high-flexibility arm up onto the tank, where it would attach itself firmly in place over an open hatch with strong magnets. The three arms then would begin to operate, each performing a different part of the ammunition-loading task.

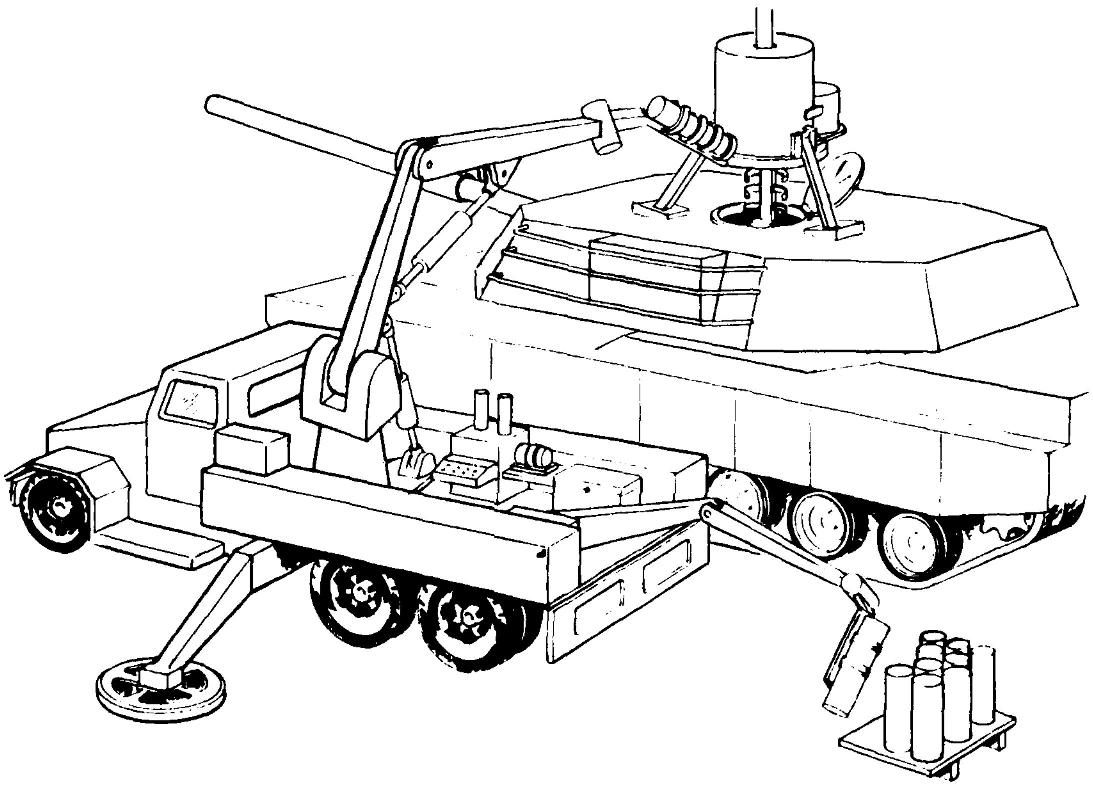


FIGURE 9 TANK AMMUNITION HANDLER DESIGN CONCEPT

4.2.5.6.1. Arms

The depalletizing arm would be especially designed to be able to cut the retaining bands from a pallet of cannisters, remove one cannister at a time, identify the type of round in it, take its top off, and pass it to the loading arm. It would use some auxiliary equipment mounted nearby on the frame to help in these tasks.

The loading arm would be designed to be able to take an opened cannister, with a round still inside it, from the depalletizing arm and hand it up to the high-flexibility arm (Figure 10), the loading arm would tip the round out of the cannister into the high- flexibility arm's gripper. Finally, it would discard the shipping cannister.

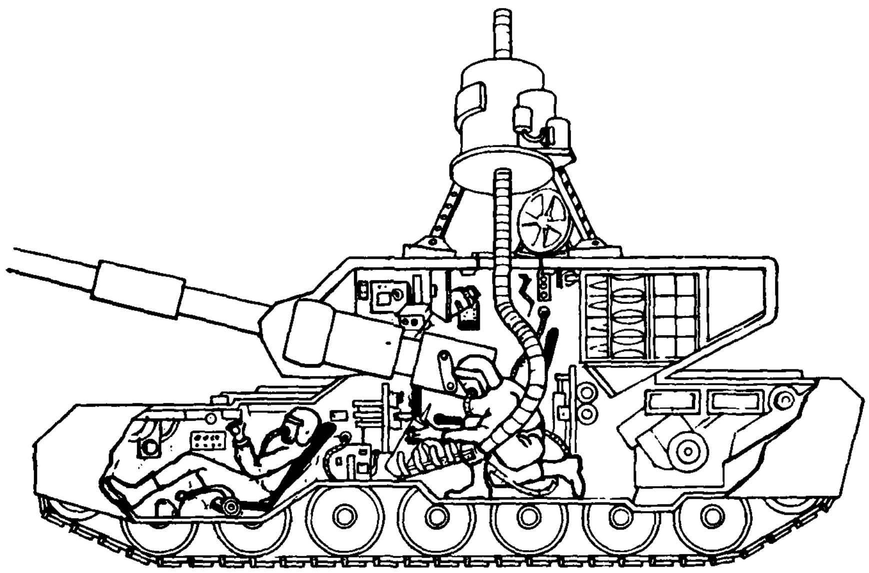


FIGURE 10 TANK AMMUNITION HANDLER HIGH FLEXIBILITY ARM

The high-flexibility arm would carry the round down through the hatchway and into the tank, to a point near the rack that is being loaded. There, a crewmember would take the round and manually insert it into its proper place in the storage rack. Before the arm retracts, the crewmember could also take a spent cartridge or dud round from the rack and put it into the gripper to be carried out and discarded.

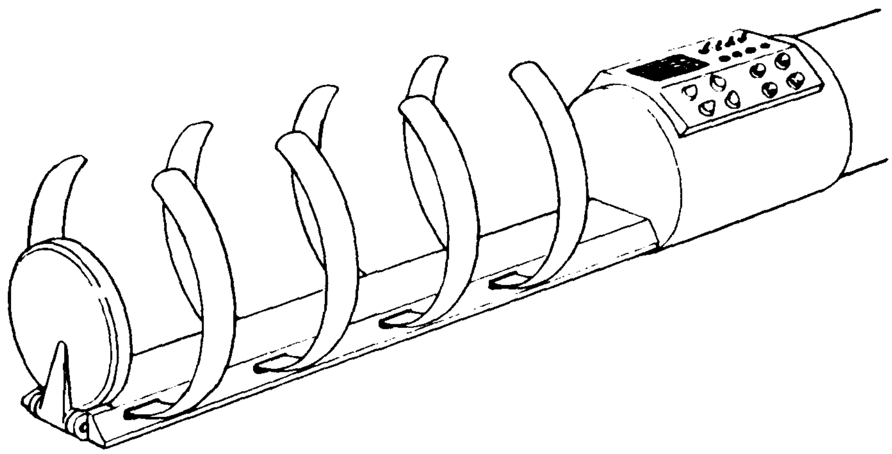


FIGURE 11 GRIPPER FOR LOADING ARM AND HIGH FLEXIBLITY ARM

This arm should be flexible enough to get around the various pieces of equipment in the crowded interior of the tank. It would consist of a multisegment arm portion, that would slide vertically through a collar that stands on several legs just outside the hatch. At the base of each leg would be a controllable permanent magnet that could attach itself to the iron of the tank body or turret. (If nonmagnetic armor should cover that spot on the tank, a large suction cup could replace the magnet.)

The high-flexibility arm would probably be rather slow-moving compared to the other, more conventional arms, and, thus, probably be the limiting element of the loader's speed of operation. If that were true, the robotic system could be configured with two or three of the high-flexibility arms on board, so that it could load that many tanks simultaneously. Then the bottleneck would probably be the depalletizing and pallet handling activities. It would be necessary to support the robotic system with an ammunition supply vehicle that could hold several basic loads and supply a round on demand about every ten seconds.

If the tank had to button up unexpectedly (due to conventional or chemical attack), the high-flexibility arm could go limp and be retracted quickly, but a crew member would be required to help guide it out. Once the arm cleared the hatch opening, the hatchcover could be closed.

4.2.5.6.2. Grippers

Figure 11 shows the gripper of both the loading arm and the high-flexibility arm. Several flexible, pneumatic, prehensile fingers would hold a cannister or round firmly, but with no danger of squeezing too hard and deforming it, as a mechanical gripper might. The compliant fingers would also adjust automatically to the shape of a cannister or round, enabling the robotic system to handle different types and calibers of ammunition.

4.2.5.6.3. Sensors

The device would have a video camera for use in finding the cannisters that the depalletizing arm is to grasp. For simplicity, the existing cannister marking could be augmented with simple codes identifying the different rounds they contain. This would enable the use of existing vision systems for identifying a small number of objects.

4.2.5.6.4. Interface

The Tank Ammunition Handler would normally communicate with the loader inside the tank through a wire data link to take the order for ammunition or to advise him of any operating problems. At any time during loading, the loader could ask the robot to bring a particular type of round next. These would be simple voice commands that could be processed with current speech-recognition technology. The loader could also use an input device mounted on the gripper of the high-flexibility arm for this communication. This might be a simple keypad or a microphone.

4.2.5.7. Logical Design

The control software for the loading arm and the high-flexibility arm could be relatively simple, because the crew member could easily train their motions. They would only have to repeat those motions, and would need only minimal sensory feedback.

4.2.5.8. Technology Gaps

Sensing

* Tactile sensors for touch, such as artificial skin
* Tactile sensors for force/torque

Effecting

* Mechanical arms
* End effectors such as hands, fingers

Manipulators

* Planning and monitoring manipulator actions, e.g., planning how to assemble something
* Planning and controlling arm movement: trajectory planning and monitoring
* End effector planning and monitoring, e.g., grasping, placing peg in hole
* Automatically detecting unexpected occurrences and malfunctions and recovering from them

Language Interpretation

* Interpreting language that is "ungrammatical", e.g., slang or dialect
* Interpreting uncertain input (e.g., speech)
* Recognizing continuous speech

Supporting Technologies

* Arm, leg, and gripper components
* Voice input with high level noise background
* Semiconductor circuits such as VHSIC

4.2.5.9. Evolutionary Versions

This device could be fielded in three stages:

* Loading arm only
* Loading and depalletizing arm
* Complete system.

4.2.6. Mine Clearer

4.2.6.1. Description

The Mine Clearer would be an autonomous vehicle designed to aid the combined arms team in breaching minefields of all types. It would be equipped with sensors and mine neutralizing devices that would permit it to rapidly traverse mined areas, avoiding mines if possible, neutralizing them if necessary, and marking the resulting safe lanes.

4.2.6.2. Needs

The enemy employs mines to disrupt and slow forces trying to penetrate his positions. Mines are normally employed in groups and cover the front lines in both breadth and depth. Doctrine dictates that minefields are always covered by fire.

The breaching of such a minefield is both dangerous and time-consuming. Friendly troops must quickly breech the minefield in order to maintain the momentum of the attack and preclude being pinned down and delayed. Therefore, a device is needed that quickly and efficiently clears a path while at the same time, does not expose the friendly combined arms team to either the effects of mines or to the enemy covering force.

4.2.6.3. Employment Concept

In the offense, Mine Clearers would be employed in teams of two, accompanying forward elements of the combined arms team. One of the Mine Clearers would be deployed with the forward echelons prepared for offensive combat. Upon detecting of an enemy mine area and deciding to

cross it, the forward team would activate the Mine Clearer to provide a clear path through the minefield of sufficient width to allow prompt safe passage of the area by the forward element (platoon size). The second Mine Clearer would accompany the rest of the unit, widening the path to permit more rapid crossing. The first Mine Clearer would continue accompanying the unit and the second would remain behind to continue widening for following elements, systematically broadening the path to four-or-five-vehicle width. The Mine Clearers continue to leapfrog until the unit halts its offensive. If necessary, the minefield paths would be further broadened by reserve elements, using other Mine Clearers.

During movements when it was not actually performing clearing operations, the Mine Clearer would be teleoperated to follow one of the mechanized vehicles of the combined arms team.

4.2.6.4. Capabilities

During clearing operations, the Mine Clearer would move at a fast rate, avoiding mines wherever possible and marking the lane as it traverses the minefield. Its on-board sensors would allow it to act autonomously, stopping only to disable mines it could not avoid. It would be able to identify and recognize standard mine patterns and detect and disable all types of antipersonnel and antitank mines.

During movement, when it was not actually performing clearing operations, the Mine Clearer would be capable of cross-country speeds comparable to the supported units maximum rate of advance (on the order of 40 km/hr). Its range would be comparable to other mechanized vehicles in the combined arms team.

4.2.6.5. Organizational Distribution

The Mine Clearer would be a TOE item assigned to the combat arms team on the basis of two per armor or mechanized infantry battalion. They would be operated by battalion personnel and maintained in engineer channels.

4.2.6.6. Physical Design

The Mine Clearer (see Figure 12) would be an autonomous vehicle consisting of several devices mounted on a horizontal frame. In order from the front of the machine to the back, they are

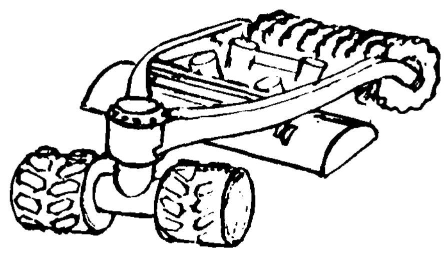
* A mine detector. This would be a multisensor device, able to integrate indications from several kinds of sensors, such as acoustic, electromagnetic, and optical, and subsurface tactile probes to recognize surface mines and locate buried mines. Based on assessment of these data, the Mine Clearer would elect either to alter its crossing path or neutralize the detected mines.
* A blastproof roller and signature simulator that would detonate most mines, both antipersonnel and antitank. To make it easier to steer, and to allow it to conform more closely to the terrain, the roller might consist of a stack of discs on edge. Each disc would be hydrostatically sprung to exert the same ground pressure.
* A demolition mechanism for destroying mines in place, also under armor.
* A drive mechanism.

4.2.6.6.1. Locomotion

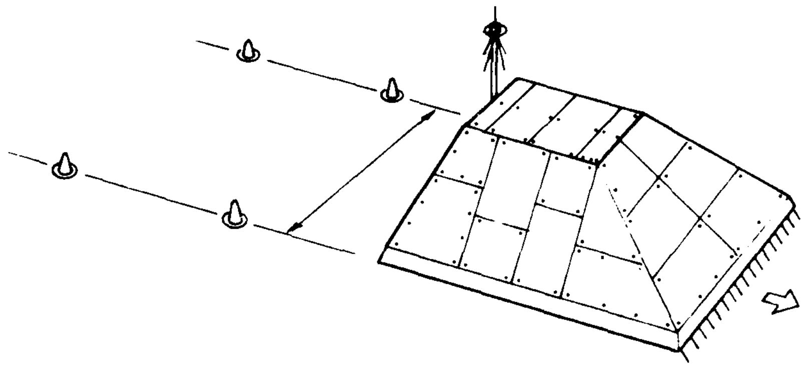
The roller would be in constant contact with the ground and support the front of the frame, which in turn would support the other devices. The drive mechanism would support the rear of the frame. All the devices would be slightly wider than the widest vehicle that would use the cleared path.

4.2.6.6.2. Special Devices

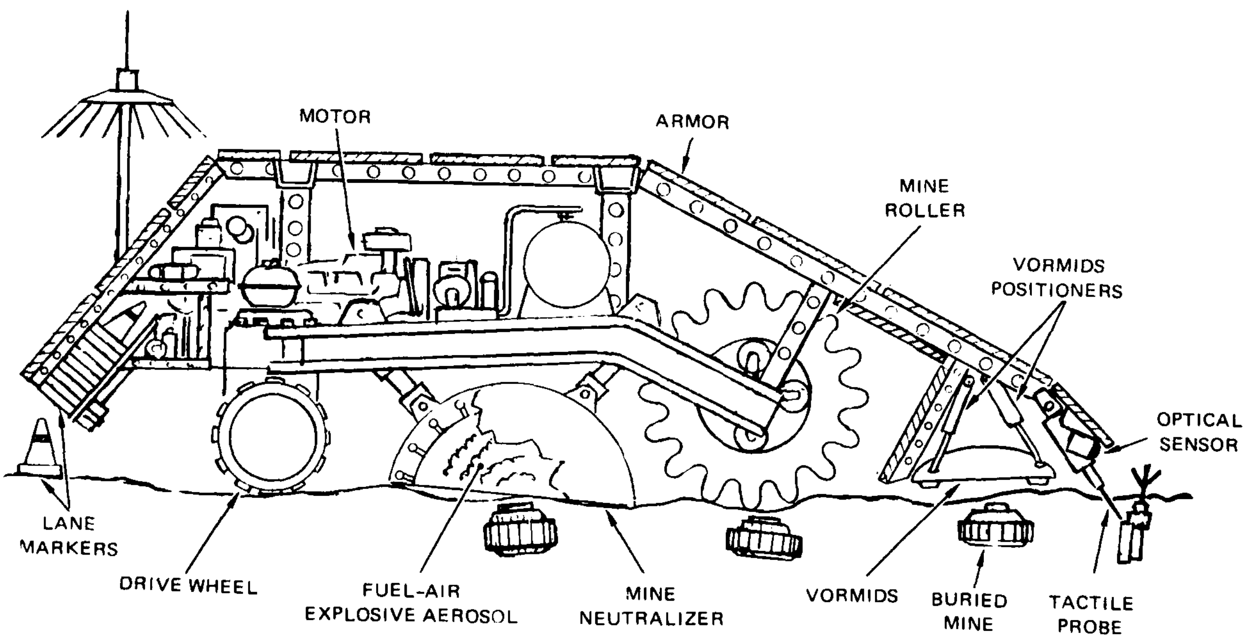
The mine-demolition device would consist of an armor-lined cylindrical cap that the Mire Clearer places over the mine. It would then pump fuel through spray nozzles into the space under the cap to fill it with an explosive fuel-air aerosol. It would then detonate the mixture at many places over the inner surface of the cap simultaneously with multiple spark plugs. This would cause a focused shock wave to propagate radially towards the center of the cap, delivering a large impact to the mine there, and inducing a sympathetic detonation in its



MAIN CHASSIS
(SHOWING STEERING METHOD)



EXTERNAL APPEARANCE



CROSS-SECTIONAL VIEW

FIGURE 12 MINE CLEARER DESIGN CONCEPT

explosive charge. Shock absorbers between the cap and the frame would absorb the impacts of the fuel-air explosion and the explosion of the mine.

This procedure should destroy most mines. In those cases where it fails (i.e., the mine detector shows that the mine is still there), the Mine Clearer would modify its route to bypass the mine.

At periodic intervals along the path, the Mine Clearer would mark the cleared path by ejecting plastic cones or light sticks. Any path marked as cleared would have been proofed in two different ways: with the mine detector and with the roller. Thus, the probability of a missed mine would be reduced to an acceptably low level.

4.2.6.6.3. Sensors

Multiple sensors would be available for surface mine detection, including vision, infrared, millimeter radar, acoustic ranging, laser scanning, probes, and metal detectors. Underground mines present more difficult problems. Some instruments to consider in addition to the Army's Vehicular Off-Road Mine Detection System (VORMIDS) include the gamma-ray backscatter sensor and the gas chromatograph to analyze the chemical composition of the object.

4.2.6.6.4. Power

The Mine Clearer would have a conventional gasoline or diesel engine.

4.2.6.7. Logical Design

The principal logical components of the Mine Clearer would be a navigation system that would attempt to find a route through the mine field, disposing of mines when necessary, and a mine-recognition system that would locate and identify mines. These components are illustrated in Figure 13.

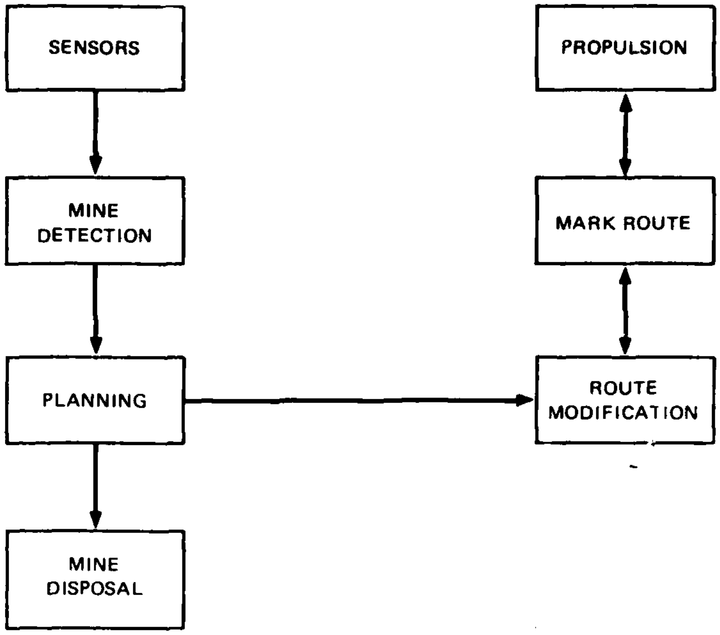


FIGURE 13 LOGICAL COMPONENTS OF THE MINE CLEARER

4.2.6.7.1. Mine Recognition

The component for locating and identifying mines would incorporate techniques for interpreting visual and other sensory information in order to recognize and identify objects. This would require multi-sensory integration and image processing. Some techniques are already available, others will have to be developed to detect buried mines, and other unusual situations.

4.2.6.7.2. Navigation

The navigation component of the Mine Clearer would be responsible for finding a path through the mine field, avoiding minor or other obstacles, or deciding to disable mines as necessary. This requires the ability to plan and follow a route. One of the major aspects is deciding for each mine whether to go around it or somehow dispose of it. Simple navigation (route planning) techniques, as discussed in

Section 4.2.11, could be used to decide the relative merits of stopping to disable a mine versus going around it. As the clearer moves, it would mark the path. If it must back up to avoid an obstacle, markings would indicate the altered path.

If a mine is to be disabled, the clearer must decide how best to do that. The decision to employ the demolition device used in this concept could be based on simple non-AI-type techniques. However, in the future, more disposal methods for new types of mines might be developed and the decisions about which to use may be complex. In that case, artificial intelligence type planning and decision-making methods will be incorporated into the system.

4.2.6.8. Technology Gaps

The main technology gaps of the Mine Clearer are:

Sensing

* Tactile sensors for probing and for touch, such as artificial skin

Mobility Control

* Route planning and monitoring
* Steering
* Automatically detecting unexpected occurrences and malfunctions and recovering from them

Computational Vision

* Representing knowledge about objects (particularly shape and spatial relationships) and developing methods for reasoning with that knowledge
* Understanding the interaction between low-level information and high-level knowledge and expectations and developing methods for combining the two
* Detecting the presence of an object or event
* Recognizing objects, including reliable IFF
* Locating objects

Information Assimilation

* Combining information from multiple sensors
* Determining what information to acquire to help establish the certainty of information
* Combining and reasoning with incomplete and inconsistent information

Action Planning

* Reasoning about alternative actions
* Reasoning about actions in different situations
* Evaluating alternative plans under varying circumstances
* Reasoning fast and efficiently when the situation changes
* Route planning and following
* Planning to acquire information

Situation Monitoring

* Plan-execution monitoring
* Detecting that a planned action has not been successfully executed
* General situation monitoring

Supporting Technologies

* Sensors for determining position and orientation in the battlefield
* Sensors for locating mines
* Sensors for detecting nearby (within approximately 10 m) objects
* Solid-state color TV cameras
* Power supplies: batteries, fuel cells, nuclear generators
* Semiconductor circuits such as VHSIC

4.2.6.9. Evolutionary Versions

A short-term version of a Mine Clearer employing teleoperation and projected line charges may be feasible. A demonstration program for this approach is underway in DARCOM. This demonstration Mine Clearer is capable of breaching an enemy minefield in either a hasty or deliberate

mode. In the hasty mode, the Mine Clearer becomes vulnerable to enemy countermeasures because it is on the back azimuth of the line charge explosion and can be targeted. In the deliberate mode, it propels the line charge which is either delay fuzed or command detonated, allowing the Mine Clearer to stand off and not be located by the back azimuth.

4.2.7. Tactical Threat Projection System

4.2.7.1. Description

The Tactical Threat Projection System (TTPS) would be an artificial intelligence system intended for internal use at division and higher headquarters. It would be integrated with other automated software and hardware components of the division headquarters. Based on continuous data inputs on the tactical situation, the TTPS would be able to project and isolate the most probable courses of action of enemy forces, and the manner in which the threat could manifest itself.

4.2.7.2. Needs

In order to defeat a numerically superior enemy force with a doctrine of continuous combat, the tactical commander must have the capacity and the opportunity to employ decisive firepower and maneuver. One of the major elements contributing to this is timely combat intelligence, which is needed to influence the course and outcome of the battle. The Tactical Threat Projection System, by integrating knowledge of enemy doctrine and tactics with real-time intelligence would assist in the rapid identification of enemy courses of action, including follow-up echelon plans. Friendly assets could then be focused on the targets most critical to enemy success, and decisive countermeasures could be employed with advantageous lead time.

4.2.7.3. Employment Concept

The Tactical Threat Projection System would have the capability to assess and project threats, providing alternatives for countering a particular threat posture. This would include the threats associated

with force-on-force situations as well as the possible enemy employment of NBC, artillery deployment, air defense, attack helicopters, EW, enemy advantages and vulnerabilities, and deviation from doctrine.

Based on a threat projection assessment, the TTPS would identify as many feasible options as possible and would provide as much lead time as possible for countering evolving tactical threat situations. This would include advice on the employment of countermeasures (when, where, and how), the most advantageous use of terrain, and the advantages and disadvantages of tactical options in light of the opposing threat.

The TTPS would automatically assimilate as much of its needed data as possible from other automated C^2 components; additional input would be provided by keyboard entry.

4.2.7.4. Capabilities

The TTPS would be capable of operating as an integrated part of automated division command and control elements. It would be capable of near-real-time analysis and output, based on continuous monitoring of the tactical situation and intelligence inputs.

4.2.7.5. Organizational Distribution

Used at division headquarters, the Tactical Threat Projection System would be a module integrated with other present or planned C^2 systems, such as the All Source Analysis System (ASAS). One operator and one alternate would be trained as part of their regular duties. Maintenance would be performed within the normal organizational structure.

4.2.7.6. Physical Design

The Tactical Threat Projection System would use the following hardware:

* Color displays
* Multiple input and output devices such as keyboard, digitizing tablets, and speech recognizers and synthesizers.

To the maximum extent possible, hardware for the TTPS would be integrated with other divisional automated C^2 components.

4.2.7.7. Logical Design

Figure 14 illustrates the components of the Tactical Threat Projection System.

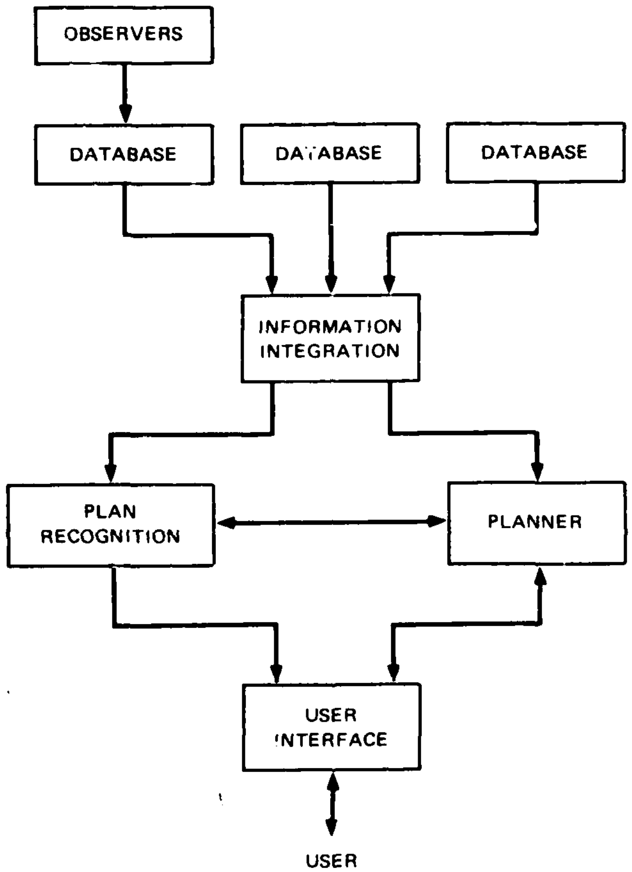


FIGURE 14 LOGICAL DESIGN OF THE TACTICAL THREAT PROJECTION SYSTEM

4.2.7.7.1. Databases

The information used for tactical threat projection would be spread over a number of large databases. It would include up-to-date intelligence information on areas such as enemy status, position, and

movements. In addition, information about enemy doctrine, past actions, etc. would be available. Some of this information might be used for other purposes, such as a planning aid for a brigade or other commander. The format of the databases could be varied as long as an interface was provided so that each database would be accessible by the systems using it.

4.2.7.7.2. Information Integration

This component would contain techniques for combining the information that was available in the various databases. Since that data might be uncertain, incomplete and possibly conflicting, methods for integrating it would have to be devised for this purpose. The integrated databases would then be used by the plan recognition and planning components.

4.2.7.7.3. Plan Recognition

Plan recognition techniques would be used to infer enemy plans and goals. Development of these techniques is still in the basic research stages.

4.2.7.8. Planner

Planning, such as described for the Brigade Mission Planning Aid, would be used to determine the actions available in a given situation. If there were several alternatives, the planner would be used to assess their relative likelihoods and suggest actions accordingly.

4.2.7.8.1. Interface

The interface to the user would be essentially the same as that described for the Brigade Mission Planning Aid.

4.2.7.9. Technology Gaps

In addition to the gaps in planning and user interfaces, the following areas require further research:

Information Assimilation

* Combining information from multiple sensors
* Combining information from multiple databases
* Combining new information with existing information
* Determining that information is lacking
* Determining what information to acquire to help establish the certainty of information
* Combining and reasoning with incomplete and inconsistent information

Situation Monitoring

* Recognizing if the information obtained has achieved the desired goal
* Detecting that goals have been accomplished based on reported actions
* Detecting that a planned action has not been successfully executed
* Detecting important changes in a situation
* Inferring a plan based on observations of individual actions

Action Planning

* Reasoning about alternative actions
* Reasoning about actions in different situations
* Reasoning about actions with strict time requirements
* Evaluating alternative plans under varying circumstances
* Comparing current plans with historical information

Language Interpretation

* Interpreting extended dialogs and text where meaning depends on the context
* Interpreting indirect or subtle utterances, such as recognizing that "Can you reach the salt" may be a request to pass it

* Interpreting language that is "ungrammatical", e.g., slang or dialect
* Interpreting uncertain input (e.g., speech)
* Recognizing continuous speech

Language Generation

* Tailoring information to fit an individual's needs
* Deciding what words and grammatical constructs to use
* Participating in a dialog--when the information is stored as "words" e.g., database, when information is stored as maps, charts, etc.
* Constructing together coherent bodies of text (paragraphs or more)
* Presenting an appropriate mix of graphic and verbal information

Supporting Technologies

* Semiconductor circuits such as VHSIC

4.2.7.10. Evolutionary Versions

State-of-the-art AI techniques could be incorporated in planned ision C^2 systems, in areas such as database access.

4.2.8. Safe Return Controller

4.2.8.1. Description

The Safe Return Controller would be an intelligent system that could assume control of an Army helicopter or airplane when the pilot became disabled. The Controller would stabilize the aircraft, assume a predetermined safe altitude and return control to the autopilot to return to a friendly airfield. It could be overruled by the pilot until it again senses pilot dysfunction. The system could be an avionics component that would use information from other aircraft instruments. It would employ any available autopilot system as an aid in implementing the actions it decided to take.

The system would allow for the consideration of eliminating the copilot (where applicable), and allow the recovery of an aircraft that, except for a disabled pilot, would be able to fly or, in the case of a helicopter, to gyro-rotate to the earth.

4.2.8.2. Needs

The ability to safely recover an aircraft when the pilot became disabled, would conserve valuable Army resources. In addition to aircraft, passenger and crew lives could be saved. When the system fully evolved, the copilot might be replaced. This latter factor indicates the potential for a significant savings in manpower and system life cycle cost.

4.2.8.3. Employment Concept

The AI Safe Return Controller would be an aircraft backup to temporarily replace the pilot should he become disabled. Its function would be to allow an aircraft without a functioning pilot to return safely.

When the Safe Return Controller sensed the conditions that indicated the pilot was not properly piloting the aircraft, it would announce that it would assume control of the aircraft. Should the pilot not be disabled, he would cancel the controller. This notice would alert the pilot to a flight problem and require a positive response. Should the pilot not respond, the controller would immediately identify the critical flight problem (as a pilot would), and determine an appropriate course of action to stabilize the aircraft. The next function, possibly taken in conjunction with the stabilization, would be to perform a safe, but radical, escape movement. This could be an immediate climb to altitude. The next function would be orientation--finding the geographical location of the aircraft in conjunction with known physical objects or beacons and selecting a return route. The final function would be to set the autopilot to return along the chosen route to a friendly airfield.

4.2.8.4. Capabilities

The Safe Return Controller would be guided by an artificial intelligence system that would have the capability of detecting possible malfunctions and making the appropriate control adjustments, to return an aircraft safely to friendly control. This implies the ability to sense aircraft handling problems, to recognize proper settings of aircraft controls and alternate settings, to compensate for aircraft mechanical problems, to retain orientation concerning present location and location of home base for safe return, and to handle flight problems such as obstacle avoidance, speed, and altitude choices. Essentially, the system must be able to perform these in-flight activities as well as a pilot.

4.2.8.5. Organizational Distribution

This system would be installed as a component on Army aircraft that were expected to be operated in forward areas. Priority would be given to those aircraft having copilots whose main function is pilot emergency backup.

4.2.8.6. Physical Design

The controller would be a small component containing the following:

* A computer.
* An interface to the pilot's instruments, the autopilot and other controls.
* A simple speaker box or warning light to alert the pilot when it detects a problem.
* A disabling switch for the pilot to react to an alert.

4.2.8.7. Logical Design

The role of artificial intelligence in this system would be to augment an autopilot with the capabilities to recognize a problem (or potential problem), diagnose its cause, and take some corrective action.

The operation of the controller would be closely coordinated with onboard sensors, instrumentation, and the autopilot. Figure 15 illustrates the logical components of the system. The onboard sensors and autopilot are included in the diagram to show their logical relationship w'th the rest of the system. They are not considered part of the artificial intelligence system.

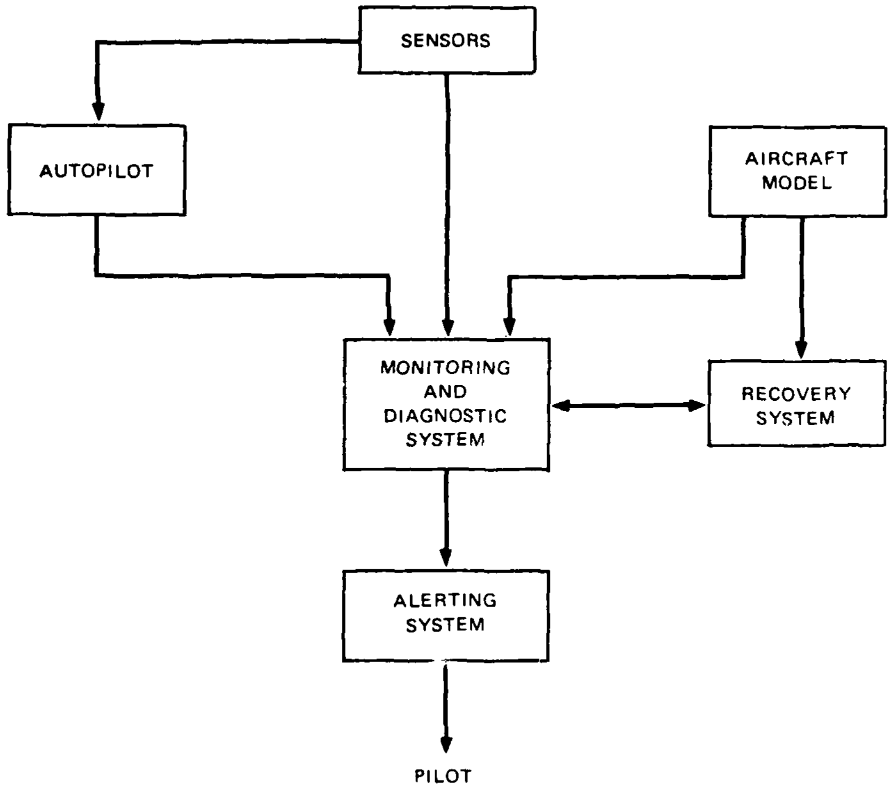


FIGURE 15 LOGICAL DESIGN OF THE SAFE RETURN CONTROLLER

4.2.8.7.1. Monitoring and Diagnostic System

The monitoring and diagnostic component of the controller would be responsible for monitoring the onboard sensors, detecting a problem or potential problem, and determining its cause.

An approach would be to specify a 'normal range' of readings for each sensor. Whenever any of them left that range, an expert system

would start operation. Section 4.2.11.1 describes an expert system component. For the controller, the expert system would use rules about sensor ranges to determine if there actually was a problem. Different rules might be developed for different aircraft, but the rest of the device would be the same for all of them. The rules would be augmented by a description of how the aircraft should work, to be used for more general reasoning when the rules proved insufficient.

Since the situation would be changing rapidly, many of the rules might concern changes in readings (e.g., rapid drop in altitude). For example, if the aircraft's airspeed drops rapidly, the expert system might be activated and rules related to drop in airspeed would be consulted. If the expert system diagnosed a problem, then the alerting and recovery systems would be activated.

4.2.8.7.2. Alerting System

When a problem was detected, an attempt would be made to alert the pilot using one of the commercially available voice output systems. The pilot could be told the problem and given a certain period of time in which to react by pushing a button, or moving some control. If the pilot reacted correctly within the prescribed time period, no further action would be taken by the controller. However, if the pilot did not react, the system would assume pilot disability and the automatic recovery system would attempt to remedy the problem.

4.2.8.7.3. Recovery System

The role of the recovery system would be to correct a potentially dangerous situation and, once that had been accomplished, set the autopilot to return to base. The recovery system would use a planning and plan-execution monitoring system to plan the actions necessary for recovery, and to monitor the execution of those actions. Section 4.2.11 discusses planning and plan-execution monitoring. The action descriptions for this planning system would include those actions a pilot could take such as adjusting airspeed and flaps.

4.2.8.8. Technology Gaps

All of the major components listed above require basic research. In addition to the gaps mentioned in the discussions of planning and expert systems there are technology gaps in the following areas:

Mobility Control

* Controlling aircraft (e.g., power, attitude) (including control theory)
* Automatically detecting unexpected occurrences and malfunctions and recovering from them

Information Assimilation

* Combining information from multiple sensors
* Determining what information to acquire to help establish the certainty of information
* Combining and reasoning with incomplete and inconsistent information

Expert Systems

* Getting the proper information into rules
* Extracting and codifying the rules for detecting aircraft handling problems
* Methods for easily changing rules
* Representing information about how a helicopter helicopter works for use in monitoring and diagnosing problems
* Representing the actions required for flying a helicopter
* Using causal models in diagnosis
* Reasoning with incomplete, uncertain, and possibly conflicting information
* Developing general-purpose expert systems that can handle a range of similar problems

Action Planning

* Planning to acquire information

Situation Monitoring

* Detecting that a planned action has not been successfully executed
* Real-time interaction between planning and monitoring

Supporting Technologies

* Semiconductor circuits such as VHSIC

4.2.9. Light Fighting Sentry

4.2.9.1. Description

The Light Fighting Sentry would augment the front line combat unit by providing sentry functions. It would carry sensors, a 7.62 mm rifle, and a grenade launcher (such as the M79). Its primary mission would be providing sentry-type functions such as warning, overwatch, or covering obstacles. It would have the capability to engage enemy troops for a short period. In the context of the air-land battle 2000, the Light Fighting Sentry would aid in providing 360-degree sentry functions to the independent combat team.

4.2.9.2. Needs

The requirements for continuous combat place a heavy demand on the combined arms team; it must be alert, ready to fight 24 hours a day. The sentry could help meet this demand by warning of impending attack or infiltration.

The Light Fighting Sentry could save casualties by substituting for a soldier in the extremely hazardous isolated roles which sentries must perform. In defensive situations, the sentry could either augment available personnel capabilities or reduce the manpower needs.

4.2.9.3. Employment Concept

The Light Fighting Sentry would be employed by combat units to provide warning of enemy activity and limited initial engagement of enemy troops. It would augment the outposting of front line troops, thereby conserving the integrity and strength of the combined arms team. In a position of defense, the Light Fighting Sentry would be lead to its primary and alternate positions forward of the FEBA.

After reaching its initial position, it would convert to a passive role until it was activated by enemy activity. It would provide basic data on enemy activity in reference to its known location, from which intelligence information concerning distance, movement speed and direction, and nature of the enemy (troops, tanks, etc.) could be derived. The data would be transmitted to a nearby APC (or MICV) where it would be recorded and displayed. Information from two or more sentries might be transmitted and interpreted at the platoon level.

Depending on its prior instruction, the sentry would either change positions on a regular cycle, on command, or when it sensed the change was appropriate for survival. Also, depending on its prior instructions, it would either act solely as an observer, or would engage enemy personnel with its weapons when it was threatened or suitable targets appeared. Engagement actions would be subject to a command override form of supervision prior to weapon firing.

The sentry would operate in a similar manner in other roles such as conducting route overwatch, or mine field or obstacle cover.

4.2.9.4. Capabilities

The Light Fighting Sentry would be capable of operation within 200 meters of the FEBA. Its passive sensors would be capable of detecting the enemy at ranges up to 500 m and transmitting immediate warning to friendly troops. It would also possess the capability of moving to a few predetermined alternate positions. It would have adequate on-board power sources to operate passively for 24 hours without servicing. Its firing capability would be limited to one load of its weapons. It could be disabled by friendly troops.

4.2.9.5. Organizational Distribution

The Light Fighting Sentry would be a TOE item issued on a basis of one per mechanized infantry squad. The APC (M113) or mechanized infantry combat vehicle (MICV) driver would be the principal Light Fighting Sentry operator. The sentry would be transported to the

vicinity of the FEBA in the APC or MICV. An information display console and communication link would be contained in the vehicle.

4.2.9.6. Physical Design

The Light Fighting Sentry should be a machine a little smaller than a man, with a low silhouette, weighing no more than about 250 pounds. Since it should be able to operate in areas where conventional vehicles cannot, such as narrow trails and the inside of buildings, legs have been proposed as the form of locomotion.

4.2.9.6.1. Locomotion

The sentry could operate its legs automatically in order to walk in a given direction at a slow speed over rough terrain. The sentry would try to keep its center of gravity as low as possible for stability and low visibility. To make this easier, and to minimize the possibility of its colliding with or catching on other objects, the sentry might have legs that telescope rather than bend. Compliant footpads and acoustic proximity sensors in the feet would allow it to walk on hard surfaces and through shallow pools of water without making excessive noise.

4.2.9.6.2. Sensors

The machine's observation sensors would be carried on a telescoping mast that would allow it to observe from a hull-down position. It would contain passive navigation equipment and 3D imaging equipment, including range finders and video cameras. It would also contain equipment that would sense if it had been illuminated by lasers or fired upon with small arms.

4.2.9.6.3. Weapons

The sentry would be armed with a selectable automatic/semi-automatic rifle and a 40-mm grenade launcher (such as the M 79).

4.2.9.6.4. Power

The sentry might be powered by a silent fuel cell with no moving parts, that would make electricity directly from hydrogen and oxygen. The hydrogen would be supplied from an internal cryogenic reservoir, and the oxygen would be extracted from the atmosphere with a semipermeable membrane. To reduce thermal signature, waste heat from the fuel cell could be captured for periods up to 1/2 hour in a fusible salt reservoir by means of a thermoelectric heat pump (Peltier device).

4.2.9.6.5. Interface to Human

To train it for a mission, a soldier would activate it through a control panel on the body, and lead it along a path to the primary and one or more alternate positions. The sentry would record the path so it could follow it in subsequent operations. Once at the positions, the soldier would use the control panel again to adjust the sentry's position and instruct it on such matters as fields of observation and fire. The sentry's control panel would have a built-in display screen to show the soldier what it was seeing, a simple speech recognition device for receiving commands, a transmission link, and a recording device to record its observations and the decisions made based on those observations.

4.2.9.7. Logical Design

Figure 16 illustrates the logical components of the sentry.

4.2.9.7.1. Navigation

As discussed in Section 4.2.11, the navigation requirements of a vehicle vary with the vehicle and the terrain. The sentry would have point positioning equipment and a terrain database so that it could reliably determine its position and orientation.

Although the sentry's routes could be preestablished, self-monitoring of its movement would be required to ensure that it stays on the route.

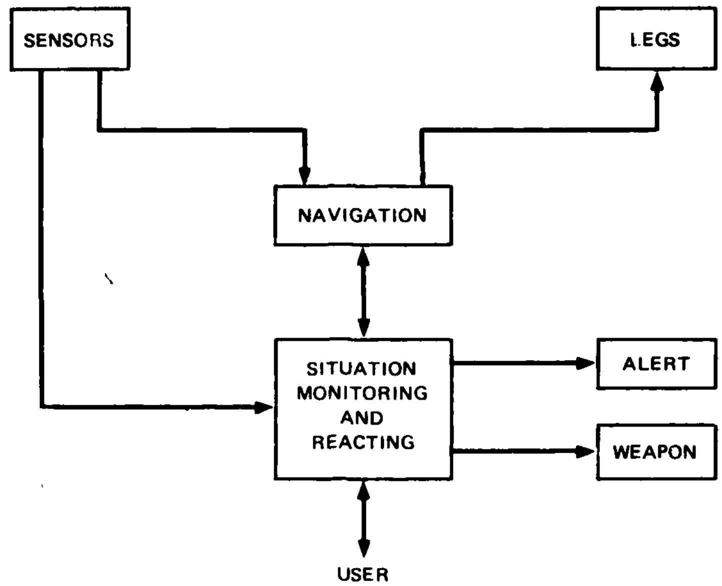


FIGURE 16 LOGICAL COMPONENTS OF SENTRY

Although it would be initially led on a path as free from obstacles as possible, the sentry must still be able to detect any obstacles that appear in the route on subsequent trips. In addition to large obstacles, it must be sure of its foot placement. Vision would be used to locate and identify objects.

The major navigation problem appears to be avoiding new obstacles that appear in the path. A simple version of the system might either just stop or retreat back along the same path.

4.2.9.7.2. Situation Monitoring and Reacting

The sentry's main duty would be to monitor a given situation, identify friends and foes (IFF), and then respond both by alerting the appropriate people and by taking simple defensive action. The same (or similar) criteria for deciding to alert someone could be used to decide to employ its weapons.

The basic monitoring cycle would be:

(1) Use current information to see if there are any likely threats around (newly-appearing unidentified objects).

(2) Determine the order in which to identify them (e.g., based on potential threat, length of time unidentified, or initial hypothesis of type of object (tank vs person)).

(3) Allocate sensors to try to make identification -- with multiple sensors, more than one object can be observed at one time if several are determined critical.

(4) If a reaction stage is reached, react.

(5) Add the newly-acquired information to the database and start the process over.

Sensor allocation could be planned much like the River Reconnaissance System's planning to gather information (as described in Section 4.2.10.7.2).

The other problem would be processing the sensory information to make the identification. This would entail combining multi-sensory information to identify objects.

4.2.9.7.3. Defensive Action

When it recognizes that it has been targeted (using current technology), the sentry could move to another location over a prespecified path. This could be a very simple non-AI design, choosing from among a prespecified set of options, perhaps on a random basis.

4.2.9.7.4. User Interface

A good interface would be required for establishing the sentry's orders. When it is at its position, the soldier could indicate the specific parts of the scene that he wants it to watch on the sentry's display of what it sees. He could also tell it what it should watch for. For example, he might outline a stretch of road on the display and say

"Report as soon as any troops or vehicles appear here."

"Report only movements in this direction."

"Monitor enemy movements and report net traffic in this direction by type of vehicle every 10 minutes."

He could also tell the machine the kind of targets it should consider engaging with its weapons, such as "moving troops," or "any moving object." If he wants it to continue observing from a different position after it does that, he would lead it to that position and tell it what to do there.

4.2.9.8. Technology Gaps

Considerable research and development is required before a device like the sentry can be fielded. The gaps in existing technology include the following:

Sensing

* Tactile sensors for touch, to help with footpads
* Tactile sensors for force/torque
* Range sensors such as laser range finders

Effecting

* Legs for locomotion

Mobility Control

* Route planning and monitoring
* Steering
* Controlling legged locomotion (including control theory)
* Automatically detecting unexpected occurrences and malfunctions during navigation and recovering from them

Computational Vision

* Representing knowledge about objects (particularly shape and spatial relationships) and developing methods for reasoning with that knowledge
* Understanding the interaction between low-level information and high-level knowledge and expectations and developing methods for combining the two
* Detecting the presence of an object or event

* Recognizing objects, including reliable IFF
* Locating objects
* Describing objects
* Detecting motion

Information Assimilation

* Combining information from multiple sensors
* Determining what information to acquire to help establish the certainty of information
* Combining and reasoning with incomplete and inconsistent information
* Planning to acquire information

Situation Monitoring

* Plan-execution monitoring
* General situation monitoring
* Detecting important changes in a situation

Language Interpretation

* Interpreting language that is "ungrammatical", e.g., slang or dialect
* Interpreting uncertain input (e.g., speech)
* Recognizing continuous speech

Language Generation

* Tailoring information to fit an individual's needs
* Deciding what words and grammatical constructs to use
* Participating in a dialog--when the information is stored as "words" e.g., database, when information is stored as maps, charts, etc.
* Constructing together coherent bodies of text

Supporting Technologies

* Sensors for determining position and orientation in the battlefield
* Sensors for detecting nearby (within approximately 10 m) objects
* Solid-state color TV cameras
* Power supplies: batteries, fuel cells, nuclear generators

* Semiconductor circuits such as VHSIC

4.2.9.9. Evolutionary Versions

The sentry could be developed and fielded in stages. Two such stages might be a version preceding the one described here, and one succeeding it.

An earlier version of the sentry could be immobile, set in place for its observation, and teleoperated rather than able to react independently. Use of weapons could be teleoperated until IFF components become available.

A more advanced version (beyond the current design) could plan its own route rather than being led.

4.2.10. River Reconnaissance System

4.2.10.1. Description

Of all the ten examples, the River Reconnaissance System is the one that requires the most research, and whose feasibility is the least certain. However, it does illustrate many interesting technological issues. The River Reconnaissance System would be a man-portable robotic device for reconnaissance of water obstacles. It would obtain up-to-date, detailed information on bank conditions, bottom conditions, depths, current profiles, and submerged obstacles in support of planning for hasty or deliberate crossing operations. In offensive situations, it would collect the information needed to select crossing sites and plan crossings, which might employ fording vehicles, assault boats, rafts or bridges. In defensive situations, it would provide similar information for use in assessing feasibility of enemy crossings and avenues of approach.

4.2.10.2. Needs

River crossing operations are among the most complex, difficult and hazardous of the tasks which face the combat units. Accurate, up-to-

date information on potential crossing sites is critical to success. For deliberate crossing efforts, such information is a prerequisite to planning the operation and assembling the proper supporting equipment. For hasty crossings, the information is essential to avoid catastrophic failures arising from choice of unsuitable sites. In fact, the availability of accurate information may be a key factor in determining whether or not a hasty crossing (which has all the advantages of surprise and maintenance of momentum) is even attempted.

In the future battlefield environment, brigade size units are expected to be operating in highly independent, isolated situations, and they may be frequently faced with the opportunities and challenges posed by water obstacles.

In defensive situations, use of water obstacles is included as an element of the overall defensive plan. It is essential to know whether or not crossings are within enemy capability and precisely where such crossings can be accomplished without extensive logistic support and time delays.

Maps, intelligence reports and terrain databases generally provide an overall knowledge of the nature of water obstacles, when they are available. Often complete information is not available at the point where decisions must be made. In addition, such information may be outdated, or not sufficiently detailed to provide a good basis for decisions. As a consequence, U.S. doctrine considers physical reconnaissance a prerequisite to crossing operations. At present, this is performed by soldiers--a highly hazardous task.

4.2.10.3. Employment Concept

The River Reconnaissance System would be employed [illegible] team. One man would be the operator and the other [illegible] to a mission, the operator would enter any available [illegible] the obstacle and a selection of mission inst[illegible] Reconnaissance System by key entry. Data may [illegible] stream velocity, bank conditions, width, [illegible]

AD-A118 297 SRI INTERNATIONAL MENLO PARK CA F/G 6/4
R&D PLAN FOR ARMY APPLICATIONS OF AI/ROBOTICS.(U)
MAY 82 D R BROWN, D V FOWLER, D J FRIE DAAK70-81-C-0250

UNCLASSIFIED ETL-0296 NL

3 OF 4
AD
A118297

Reconnaissance System would include a terrain database and this might be updated if necessary to reflect the current area of operations. Possible instructions may include number and desired spacing of entry points, number and spacing of desired exit points, release and rendezvous points, requests for search to find fordable routes, or other special features, and maximum allowed reconnaissance time.

To execute the reconnaissance, the River Reconnaissance System would be carried to a concealed position within 50 meters of the water in the general vicinity of potential crossing sites by the team, using maximum stealth and cover to conceal interest in the site. Whenever possible, the reconnaissance would be performed at night. Prior to release, last minute changes to instructions could be entered by the operator.

When released by the operator, the River Reconnaissance System would crawl to the stream bank, enter the water, perform the reconnaissance of near shore, far shore and stream conditions. It would plan its own operation to obtain the requested data, based on its internal terrain database, estimated data and instructions, and modify its plans as necessary during execution. On completion of the mission, it would return to its point of entry and crawl back to the operator, or to some other predesignated rendezvous point. All movements would be carefully made in a manner that minimizes signatures such as noise, splashing or wakes.

On return, the operator would make an immediate query to ascertain whether or not the River Reconnaissance System successfully completed its mission within the allowed time, and what data gaps, if any, remained. If desired, the operator might re-instruct the River Reconnaissance System to return to the water and collect further data.

The detailed data would be displayed or reported by the River Reconnaissance System in printed form on demand, employing a separate small communication unit attached by the operator. The report might be requested by the operator immediately for further rapid transmission, or later after return to a safe area.

4.2.10.4. Capabilities

The River Reconnaissance System should be capable of reconnoitering water obstacles up to approximately 1/2 km in width. It should ascertain bottom conditions at depths up to 4 m. (In deeper areas, it would verify freedom from obstacles at 4 m depth.) In a single mission it should reconnoiter up to 100 m of bank. It should be capable of operating on missions lasting up to one hour, and should perform two such missions on its self-contained power, without servicing.

4.2.10.5. Organizational Distribution

The River Reconnaissance System would be an item of TOE equipment in Division 86 Engineer Battalions, (three per battalion). Operators and alternates would be trained as an additional duty in the Engineer Battalion. In addition, two personnel from each Infantry Battalion in the Division would be trained as operators, and the River Reconnaissance System might be provided temporarily to brigades for employment by such personnel when the brigades are operating independently. Maintenance would be performed within the normal division structure.

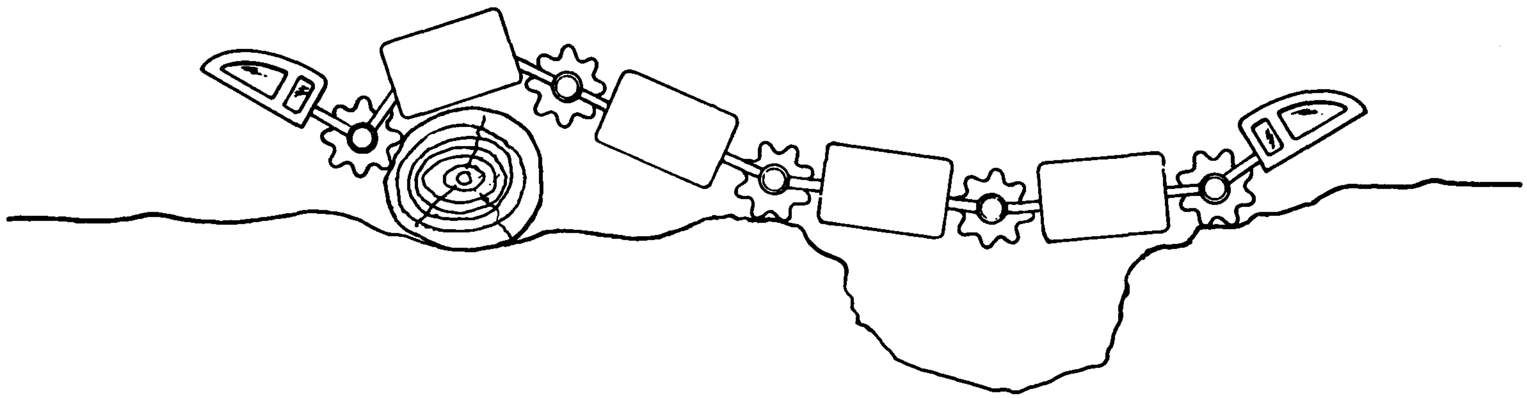
4.2.10.6. Physical Design

Figure 17 shows a design concept for the River Reconnaissance System AI/robotics system based on an articulated-body concept to emphasize stealth and mobility in a variety of terrain conditions. The machine would consist of:

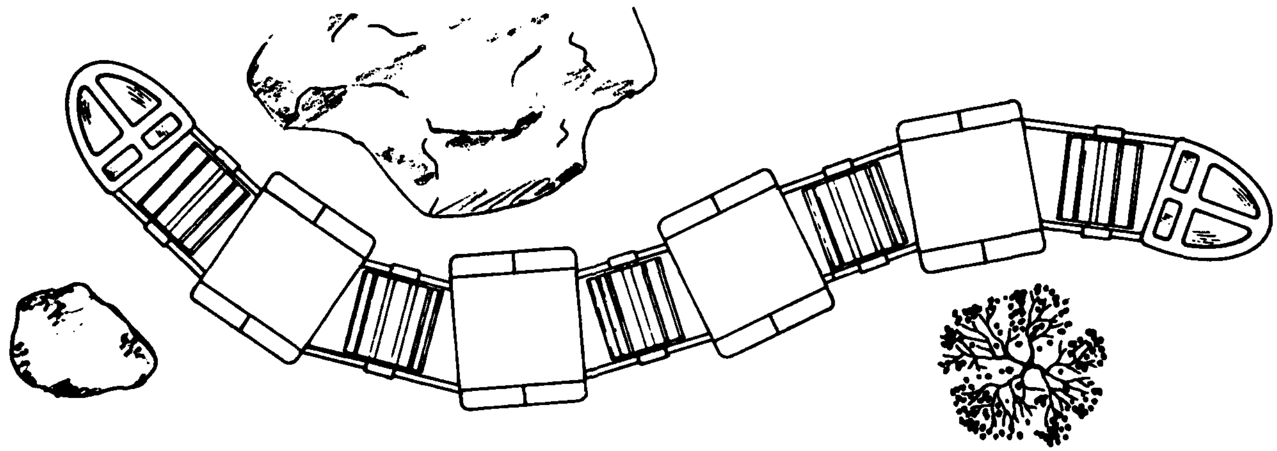
* Two identical, sensor-equipped "end segments,"
* Four body segments,
* Five broad, hollow, semi-rigid wheels, one wheel between each segment.

4.2.10.6.1. Locomotion on Land

Each wheel would be powered by a motor mounted within the wheel and forming the wheel's axle. The tread pattern on each wheel would consist of deep, rounded lobes running transversely across the tire parallel to its axle.



(a) SIDE VIEW OF RIIVERRAT SHOWING UNDULATING CAPABILITY



(b) TOP VIEW OF RIVERRAT SHOWING SNAKING CAPABILITY

FIGURE 17 RIVER RECONNAISSANCE SYSTEM DESIGN CONCEPT

A powered linkage would connect the wheels and body segments to give the machine the flexibility it would need to be able to hug the ground for minimum visibility. This design should permit it to climb over obstacles that may be almost as high as the vehicle is long. The linkages also should enable the vehicle to move on land in several different ways, to suit the terrain, such as

* By rotating its wheels (normal mode). This mode is suitable for rapid motion along roads or smooth ground, and slower crawling over obstacles. To steer, the body bends to the left or right.
* By freeing its wheels and undulating its body segments from side to side (snake mode). This mode is best suited to movement through thick vegetation or deep mud.
* By locking its wheels and sending vertical undulations along its body from back to front (snail mode). This mode is most useful on ground that is very slippery, steeply sloped, and/or unstable.

4.2.10.6.2. <u>Locomotion in Water</u>

Once in the water, the River Reconnaissance System would propel itself with four water jets, which would also be produced by the action of its wheels, as follows. The body would fold at its midpoint (see Figure 18), bringing pairs of wheels together so that the lobes on their treads mesh like gear teeth. When a pair of meshed wheels rotate they act as a gear pump, ingesting water from either side of the vehicle and pumping it outwards parallel to the axles, in both directions. Sheet metal cowlings on the tops and bottoms of the body segments would slide forward to form ducts that divert the outflowing streams to the rear, propelling the vehicle forward. The vehicle would steer either by twisting its body while moving forward or backward or by rotating its center wheel (which is located at the rear of the vehicle when the vehicle is in the folded position).

The front two segments would be equipped with two sets of cowlings, one set of which could be used to obtain reverse thrust. However, only one pair of wheels pumps water in this mode, so the maximum reverse thrust would only be approximately one half of the maximum forward thrust obtainable.

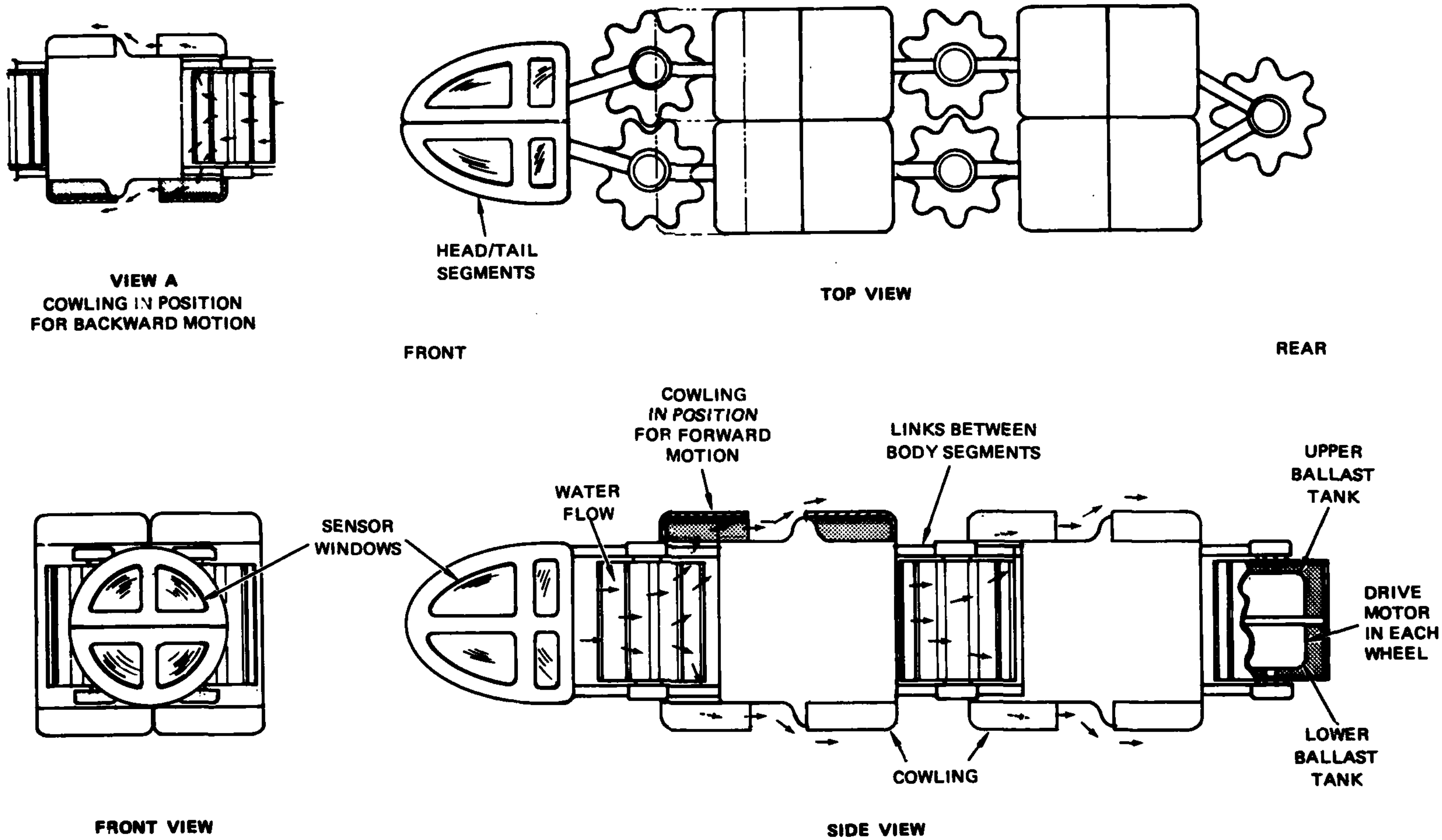


FIGURE 18 RIVER RECONNAISSANCE SYSTEM CONFIGURATION IN WATER

Finally, two air spaces in each wheel would act as flotation chambers. Connections at the axle would allow the machine to partially flood each air space to control buoyancy and trim.

4.2.10.6.3. Sensors

The River Reconnaissance System would be equipped for three main methods of sensing external conditions:

* Vision
* Sonar
* Penetrometer and other sensors for soil analysis.

These would be augmented by other sensors to aid navigation, such as inertial navigation and point positioning systems.

Vision would be used for surface navigation--whether on the ground or in the water, for visual reconnaissance of banks, and (where water and lighting conditions permit) for subsurface navigation. Sonar would be used for reconnaissance of subsurface terrain contours and also as the main method for underwater navigation. The soil analysis sensor would be used to determine the load-bearing properties of banks and the bottom.

The vision sensors would be two high-resolution solid-state color/Infrared cameras, one mounted at each end of the vehicle. A movable mirror associated with each camera would allow it to look out in any direction with hemispheric coverage. The end segments could be elevated independently to see over objects without exposing the main portion of the machine. When the River Reconnaissance System moved on land, one camera would look ahead while the other looks back. This would allow it to retreat from an exposed or partially-exposed position easily, without having to turn around. When reconnoitering, either on land or in the water, the vehicle could stretch out to its full length and direct both cameras at the same scene. This would permit highly-accurate stereographic measurement of nearby terrain contours on the banks, using a baseline of approximately the full length of the vehicle.

The River Reconnaissance System could also survey the crossing region by means of its internal navigation sensors. Infrared vision would allow it to function at night and in bad weather. The survey information could later be used to update maps or automatic navigation systems in the vehicles that will make the crossing.

Phased arrays of hydrophones would be distributed along the sides, top, and bottom of each body segment. These would allow high-resolution sonar mapping of the water obstacles in three dimensions simultaneously, once the River Reconnaissance System is in the water.

The River Reconnaissance System would have a penetrometer for soil-analysis. Other sensors may be required. Several approaches seem to offer promise. These approaches include direct simulation of the ground loading of a vehicle (perhaps by simply walking on the bottom), tactile exploration of the soil with a manipulator, gamma-ray backscatter, core sampling, and impulse seismography. Visual analysis might be practical in some cases, but it would be too easily defeated by turbidity to be relied upon entirely for soil evaluation under water.

4.2.10.6.4. Power Supply

Power consumption would be increased by having to cross difficult terrain in order to reach the water, and by swift currents in the water. In still water, such as would be encountered in a lake crossing, power consumption might be quite modest. The results of research in low-drag hull design and simulated "porpoise skin" hull coverings may also be useful in reducing power requirements when submerged.

Selection of the optimal power source for the River Reconnaissance System would require detailed evaluation studies of issues such as total power requirements, surge requirements, and shelf life. For the purposes of this report we have chosen one of the simplest power supplies, rechargeable batteries, to supply the power for the vehicle.

4.2.10.6.5. Soldier-Machine Interface

The River Reconnaissance System would receive its orders and report its findings through a high-speed data link. An electrical connection on the surface of one of the body segments would allow a soldier to plug in a portable, miniaturized keyboard/display/printer/data store/computer. The soldier would give the robot its instructions through this device and then disconnect it. On the River Reconnaissance System's return, the soldier would plug the device in again and the River Reconnaissance System would dump its collected information.

4.2.10.7. Logical Design

Figure 19 illustrates the logical components of the River Reconnaissance System.

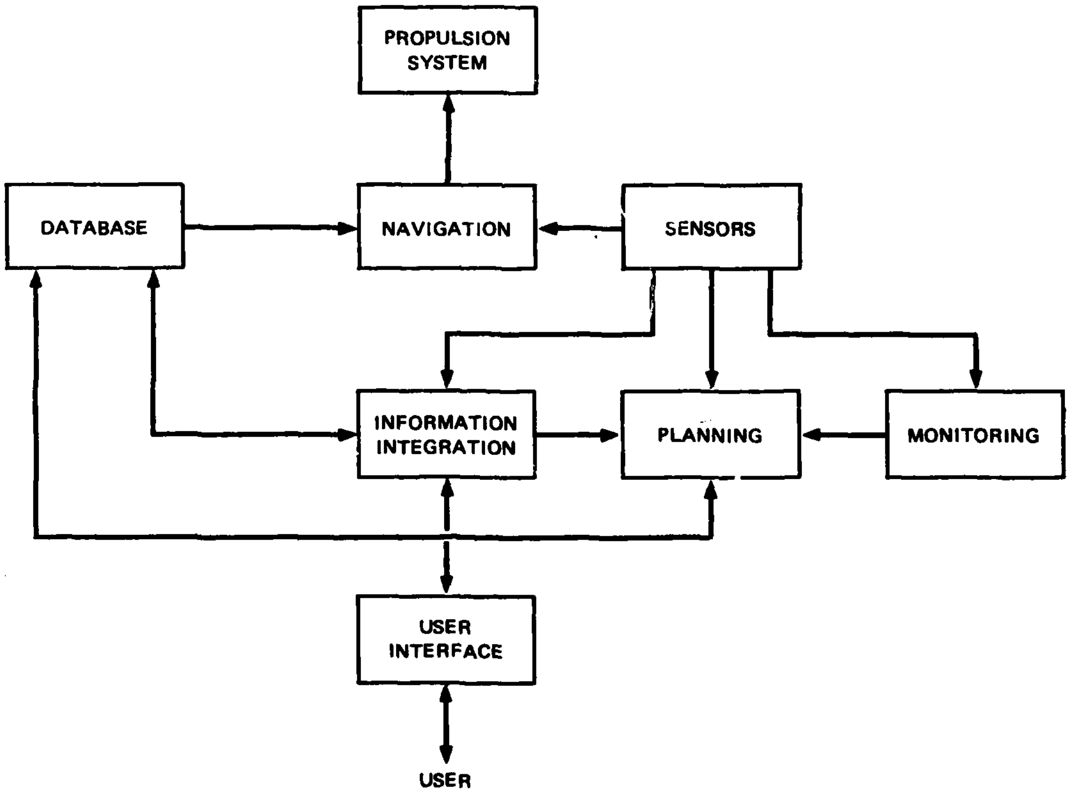


FIGURE 19 LOGICAL DESIGN OF THE RIVER RECONNAISSANCE SYSTEM

The principal role of the River Reconnaissance System would be to gather information. The major elements of that process, in addition to the sensors, are the information integration, planning, and plan-execution monitoring components. They would decide which sensors to use, where to use them, and whether the desired information has been obtained. The cycle for gathering information would be:

(1) Plan to get specific information to meet some goal (e.g., determine the river depth in some area).

(2) Execute the planned action (i.e., use the sensors and analyze the data).

(3) Monitor the execution of the action: If the goal is achieved, (e.g., the river depth determined) then try to achieve the next goal: otherwise retry this goal, unless of course it has been tried some number of times and there is little likelihood of success.

4.2.10.7.1. Planning

The general planning component is described in Section 4.2.11. For the River Reconnaissance System, the actions planned in step 1 would be to use sensors to gather information. The planner would have a description of each sensor and what information it contributes.

4.2.10.7.2. Information Integration

Existing and yet-to-be-developed information-integration techniques would be used to analyze and incorporate the newly-acquired data. This, plus the actual use of the sensors, constitute step 2.

4.2.10.7.3. Plan-execution Monitoring

A component for monitoring the execution of planned actions, as described in Section 4.2.11, would be used in step 3 to check that the action has achieved the desired goal, i.e., that the desired information has been gathered. If not, another attempt would be made.

4.2.10.7.4. Database

Available, relevant information about the river and surrounding area would be put onboard the River Reconnaissance System for use in navigation, in analysis of information gathered, and to aid in decisions about which information to gather. Data would include a terrain data base and any available estimated information on the river's characteristics.

4.2.10.7.5. Navigation on Land

As discussed in Section 4.2.11, there are a range of techniques available for navigation and a range of capabilities possible depending on the requirements of the device. Since the River Reconnaissance System requires navigational abilities both on land and in the water, these aspects are discussed separately, although there are clearly common elements.

For land navigation, the River Reconnaissance System would use available systems for positioning and orientation. The starting and ending points of its route would be given to it, although intermediate points might not be. Its main problem would be avoiding obstacles. Vision would be used to detect obstacles. The extent to which detailed recognition of obstacles and planning of detours would be required would depend on the ruggedness of the device. The main role of planning would be to avoid obstacles and to find paths between pre-specified starting and ending points.

4.2.10.7.6. Navigation in Water

Underwater navigation is more difficult, particularly in muddy or turbulent water. Although presumably the same techniques for determining position might work underwater, they can be complicated by currents that move the River Reconnaissance System. In water the River Reconnaissance System must much more closely monitor its position, perhaps relative to landmarks as well as by point positioning information, since it cannot be sure of the effects of currents and it must compensate for them in its movements.

Since vision cannot be relied on underwater, the River Reconnaissance System would use sonar data to detect obstacles in its path. Techniques for avoiding obstacles on land are applicable underwater, although some adjustments may be required.

The route planning requirements of the River Reconnaissance System underwater are slightly more complex because they interact with the information-gathering process. In a limited sense, the River Reconnaissance System must decide where to go to get the desired information, as well as how to get there. However, in this system the decisions about where to go could be made in the planning component used for information gathering and the navigation system would only plan how to get to the destination.

4.2.10.8. User Interface

The most important outputs from the River Reconnaissance System, such as bottom or route contours, and stream velocity profiles, could be displayed graphically. A low-resolution version could be shown on a small display. The data would be available for transfer to other maps and charts and to provide supporting evidence. Using a small terminal, the operator could get contour information quickly. With more computing resources and better display (and possibly more extensive hard copy) devices, more of the information collected could be accessed. For example, the data used to produce the contour map, or the sonar readings in a particular area, could be seen. A simple natural-language query system could provide the access desired -- perhaps a variation of the Division Commander's Quick Data-Access System described in Section 4.2.10.

4.2.10.9. Technology Gaps

The main technology gaps that need to be filled in the River Reconnaissance System application are:

Sensing

* Tactile sensors for touch, such as artificial skin

* Tactile sensors for force/torque, and for soil analysis
* Range sensors such as laser range finders

Mobility Control

* Route planning and monitoring
* Steering
* Controlling locomotion (e.g., legs, wheels) (including control theory)
* Automatically detecting unexpected occurrences and malfunctions and recovering from them

Language Generation

* Tailoring information to fit an individual's needs
* Deciding what words and grammatical constructs to use
* Participating in a dialog--when the information is stored as "words" e.g., database, when information is stored as maps, charts, etc.
* Presenting an appropriate mix of graphic and verbal information

Computational Vision

* Representing knowledge about objects (particularly shape and spatial relationships) and developing methods for reasoning with that knowledge.
* Understanding the interaction between low-level information and high-level knowledge and expectations and developing methods for combining the two.
* Detecting the presence of an object or event
* Recognizing objects, including reliable IFF
* Locating objects
* Describing objects
* Detecting motion

Language Interpretation

* Interpreting language that is "ungrammatical", e.g., slang or dialect
* Interpreting uncertain input (e.g., speech)
* Recognizing continuous speech

Information Assimilation

* Combining information from multiple sensors
* Combining new information with existing information
* Determining that information is lacking
* Determining what information to acquire to help establish the certainty of information
* Combining and reasoning with incomplete and inconsistent information

Action Planning

* Reasoning about alternative actions
* Reasoning about actions in different situations
* Reasoning about actions with strict time requirements
* Evaluating alternative plans under varying circumstances
* Reasoning quickly and efficiently when the situation changes
* Planning and following a route
* Planning to acquire information

Situation Monitoring

* Plan-execution monitoring
* Recognizing if the information obtained has achieved the desired goal
* Detecting that a planned action has not been successfully executed
* Real-time interaction between planning and monitoring
* General situation monitoring

Supporting Technologies

* Sensors for determining position and orientation in the battlefield
* Sensors for detecting nearby (within approximately 10 m) objects
* Solid-state color TV cameras
* Power supplies: batteries, fuel cells, nuclear generators
* Semiconductor circuits such as VHSIC

4.2.10.10. Evolutionary Versions

Earlier versions of the River Reconnaissance System could be built and fielded. For example, an earlier version might eliminate ground navigation and have a limited user interface. However, the sensing capabilities described above would still be required.

4.2.11. Common Modules

In this section, components that would be incorporated into more than one of the example systems are described. The components may not be physically distinct, but they do constitute conceptual building blocks for the systems.

4.2.11.1. Expert System

As discussed in the review of artificial intelligence in Section 3, an artificial intelligence-based expert system uses rules that go from observational data to a hypothesis about the situation. For example, in diagnosing equipment failure, the hypothesis is about the cause of the failure. There are currently several specific approaches to this type of system, and a careful study should be made to select the one most appropriate for each application. For systems that handle similar problems, the same basic expert system could be used. The difference would be in the rules encoded for each specific problem area.

The set of rules for the specific task to be performed is associated with an expert system. These rules are typically rules elicited from a person who is an expert at performing the task. Each system would have its own set of rules. The form of the rules would be determined both by the expert system used and the particular application.

Current expert system technology can be made more powerful by expanding it to include the use of a causal model, i.e., description of how the system works (see Section 3). The system will reason from this model whenever the expert's rules are not sufficient. Just as different

applications contain different sets of rules from the experts, they contain different models of how the system works. The system designs include a causal model when appropriate.

Although expert system technology is currently applicable to some problems, the following areas are some of those that require further research for expert systems to be used in many of the systems described above.

* Getting the proper information into rules
* Methods for easily changing rules
* Using causal models in diagnosis
* Reasoning with incomplete, uncertain, and possibly conflicting information
* Developing general-purpose expert systems that can handle a range of similar problems

4.2.11.2. Planning System

Artificial intelligence planning systems combine sequences of actions to achieve a desired goal. Planning systems are still in the research stage, and many approaches to the problem are being explored. Consequently, it is premature to specify any particular methods to be used. However, any planning system must have certain capabilities and it must have certain information with which to plan.

A planning system must have information available to it about the actions that can be performed (e.g., troop movement, firepower use); the effects and requirements of the actions; alternatives means of conducting them; and information about possible interactions among actions (e.g., the logistical requirements associated with troop movements).

Information about actions should be encoded in such a way that the actions that are planned can easily be modified or changed. This will provide flexibility so the same system might be used in a wide variety of situations.

The planning system should also have the information and algorithms that will provide the capabilities listed below. It should be noted that development of many of these would require further basic research in planning and related areas.

* Deduction of facts from data in the databases. There are many approaches to this. The specific one taken will depend on the particulars of the database, for example what facts are explicitly stored, and the deductions that should take place.
* Reasoning about alternative actions that can be used to accomplish a goal or goals.
* Reasoning about actions in different situations.
* Representing spatial relationships and movements through space and reasoning about them.
* Evaluating alternative plans under varying circumstances.
* Planning and reasoning with uncertain, incomplete, and/or inconsistent information.
* Reasoning about actions with strict time requirements. For example, some actions may have to be performed sequentially or in parallel or at specific times (e.g., night time).
* Replanning fast and efficiently when the situation changes.

4.2.11.3. Monitoring Systems

4.2.11.3.1. Plan-Execution Monitoring

Monitoring systems that follow the execution of a plan to see if it is being carried out successfully are often closely associated with planning systems. This type of system will look for specific situations to be sure that they have been achieved. For example, it would determine if a piece of equipment had arrived at the location to which the plan had directed it.

4.2.11.3.2. Situation Monitoring

Another type of monitoring system is one that will watch for prespecified conditions or some 'general state' whose detection might require some deduction (such as the application in the Safe Return Controller and the Light Fighting Sentry).

Many systems actually require both types of monitoring. Techniques for performing the first type are better understood, although, in general, these problems are on the frontiers of research. For specific applications, customized systems might be built, but they would probably be limited. More basic research is required in this area.

4.2.11.3.3. Navigation

The basic problems associated with the autonomous navigation application required by the example system include the following:

* Positioning and orientation.
* Obstacle and hazard detection, including terrain features that present problems to certain types of locomotion.
* Avoiding or detouring around obstacles in a path.
* Route planning and following.

Point positioning and orientation are central problems that are being addressed independent of the issues of autonomous navigation. We generally assume that systems providing accurate position information will be available. Reasonably simple computational techniques can be combined with these systems to determine the path a moving vehicle is following.

Detecting obstacles in a path can be a major problem. The requirements of a system for detecting obstacles depend greatly on the vehicle and the terrain. For example, a sturdy vehicle in flat, dry terrain may only need to detect large obstacles such as boulders or trees, which is a relatively simple task that might be done with existing techniques and sensors. Terrain features such as large pools of water, quicksand, mudholes, and dense vegetation present many more obstacles. Detecting some of these is more difficult and will require advancements in computational vision. Also, some vehicles are more sensitive to uneven ground. For example, legged vehicles may require a vision system that provides enough information to help decide where to place each foot.

Avoiding an obstacle can be a difficult problem, again depending on the terrain and the type of locomotion. When the obstacle is easily identified and stationary, and a simple detour is possible, then reasonably simple techniques can be used to navigate around it. However, detouring around some obstacles may require more global modifications to the route. For example, if a bridge across a river has become impassable, it may be necessary to find another bridge or find another means of crossing the river. This type of planning would require a more general ability to plan and follow routes.

Another problem is presented by obstacles that move. Avoiding the obstacle requires predicting its path and speed. If the movement is erratic and perhaps intended to cause problems, avoiding it could be difficult.

In the most general case, route planning and following requires deciding where to go, planning a good route to get there, and then following along that route, making changes as necessary to accommodate unanticipated obstacles or situations. Some systems will not require such sophistication, although almost any of them will require some ability to detect and avoid obstacles in a given path.

None of the ten examples discussed above requires the ability to decide where to go, although some of the other application concepts do. There are three points along the continuum of path planning abilities that are closest to the requirements in the ten examples.

(1) In the simplest case, the entire route could be prespecified. Reasonably simple computations could be used to ensure that the vehicle stays on the route, correcting for any deviation from the planned path. The major navigational problem would be in detecting and avoiding obstacles along the way.

(2) Some or all of the route is not prespecified, although the starting and ending points are. In this case, the unspecified portions of the route would have to be planned. The planning techniques described above, probably blended with operations research techniques for finding routes could be used.

(3) The most advanced capability is that of first deciding where to go, and then deciding how to get there. The

decision about destination might be affected by the difficulty of getting there, so there could be some interaction between deciding the destination and finding a route. A system that performed this type of navigational planning would most likely incorporate a planning system such as described above.

4.2.11.4. Technology Gaps

A significant technology gap exists in spatial reasoning and in identifying subtle terrain features, textures, etc.

4.2.11.5. User Interfaces

All AI systems must have a good, simple interface to all users. Generally the interaction will be in more than one medium, including voice, text, pictures, charts, and graphs. The specific medium will naturally depend on the type of information to be communicated, and the physical or other limitations on a particular system. For example, a hand-held terminal to interface to the River Reconnaissance System could not contain a high-resolution color display whereas a terminal in a vehicle might.

Within the limitations of the specific system, the interface should always accept and respond in some simple subset of English, and should also include the ability to produce maps or charts or graphs when appropriate. The Division Commander's Quick Data-Access System (Section 4.2.10) can be viewed as one kind of interface.

The following are some of the requirements of interfaces:

* One or more color displays that show maps, charts, and other graphical information.
* A simple means of interaction through voice input and output, pointing devices, the use of menus and other input-output methods.
* A good printing device for text and graphic information.

5. RESEARCH AND DEVELOPMENT PLANS

Plans for research and development in artificial intelligence and robotics are presented in this section. Sound plans for R&D in the near future that can be used immediately by the Army R&D community for planning, programming, and budgeting are the objective. The methods used for developing these plans were chosen with that objective in mind. In order to develop sound near-term plans (for the next five years), the longer-term factors need to be considered, even though they cannot be accurately foreseen. One of these longer-term factors has already been discussed at length, the possible future applications of AI/robotics in Army combat and combat support. The ten examples of Army applications were chosen because they serve as reasonable long-term objectives (approximately twenty years from the present) for the purpose of developing sound decisions in the short term. The examples are not necessarily the applications that should ultimately be developed. However, they are believed to be adequate for the present objective. Because future studies, research, and development will improve the definition and understanding of the applications, the ultimate applications may be quite different from the examples that have been described.

In this discussion of R&D plans, the approach is to start with basic research and to consider successively more applied research and development. The technology base (6.1 and 6.2) will be considered first, followed by developments. Plans for the technology base are derived from the previous discussions of artificial intelligence and robotics (Section 3) and Army application categories (Section 4). The specific research tasks to be presented are, for the most part, those that have already been identified in connection with the ten examples of Army applications.

For the developments (6.3 and 6.4), new considerations in addition to those discussed in Section 4 will be introduced here, factors that need to be considered in developing R&D plans. These factors include schedules, benefits, costs, and risks. Estimates of these factors will be presented for each of the ten examples of Section 4 to provide a basis for evaluating the research tasks in the technology base and deciding which research tasks should have higher priority. In addition, the evaluation will consider the possible development of Army AI/robotics applications that could be initiated with the present technology base. For these possible developments, alternative versions of some of the examples will be considered, versions less ambitious than the examples that have been described. The consideration of alternative versions will be limited to the ten examples. Consideration of all the possible Army applications, as represented by the 100 application concepts discussed in Section 4 and Appendix A, would clearly be desirable, but such consideration is beyond the scope of this report.

5.1. Technology Base

This discussion of the technology base is organized primarily according to the unified model for artificial intelligence and robotics presented in Section 3.

5.1.1. Fundamental Research Topics

A few fundamental research (FR) topics underlie other research and development in AI/robotics. They support all ten examples, as well as the 100 application concepts described in Appendix A, and are listed in Table 20.

Table 20

FUNDAMENTAL RESEARCH TOPICS

Topic No.	Topic
FR1	Representing knowledge about the world, including spatial relationships and movement
FR2	Acquiring and explaining knowledge
FR3	Reasoning: drawing conclusions, making decisions
FR4	Techniques for reasoning with uncertain, incomplete, and/or inconsistent information
FR5	Evaluating and choosing among alternatives

5.1.2. Specific Research Topics

The specific research topics, for the most part, are the ones that were identified in the previous discussions of the ten examples, in Section 4.2. This is the rationale for including them in Table 21. The table includes an indication of the examples that are supported by that topic.

Table 21

SPECIFIC RESEARCH TOPICS

Topic No.	Topic	Example(s) Supported
Sensing		
S1	Tactile sensors for touch, such as artificial skin	5, 6, 9, 10
S2	Tactile sensors for force/torque	5, 9, 10
S3	Range sensors such as laser range finders	9, 10
S4	Sensors for locating mines	6
Effecting		
E1	Mobility mechanisms such as legs	9
E2	Mechanical arms	5
E3	End effectors such as hands, fingers, and tools	5
Manipulators		
M1	Planning and monitoring manipulator actions, e.g., planning how to assemble something	5
M2	Planning and controlling arm movement: trajectory planning and monitoring	5
M3	End effector planning and monitoring, e.g., grasping, placing peg in hole	5
M4	Automatically detecting unexpected occurrences and malfunctions and recovering from them	5
Mobility Control		
MC1	Route planning and monitoring	6, 9, 10
MC2	Steering	6, 9, 10
MC3	Controlling locomotion, e.g., legs, wheels (including control theory)	8, 9, 10

MC4	Automatically detecting unexpected occurrences and malfunctions and recovering from them	6, 8, 9, 10

Language Generation

	What to say:	
LG1	Tailoring information to fit an individual's needs	1-4, 7, 9, 10
	How to say it:	
LG2	Deciding what words and grammatical constructs to use	1-4, 7, 9, 10
LG3	Participating in a dialog--when the information is stored as "words" e.g., database, when information is stored as maps, charts, etc.	1-4, 7, 9, 10
LG4	Constructing coherent bodies of text (paragraphs or more)	2, 7
LG5	Presenting an appropriate mix of graphic and verbal information	2, 3, 7, 10

Computational Vision

	Basic research:	
CV1	Representing knowledge about objects (particularly shape and spatial relationships) and developing methods for reasoning with that knowledge	6, 9, 10
CV2	Understanding the interaction between low-level information and high-level knowledge and expectations and developing methods for combining the two	6, 9, 10
	Applications:	
CV3	Detecting the presence of an object or event	6, 9, 10
CV4	Recognizing objects, including reliable IFF	6, 9, 10
CV5	Locating objects	6, 9, 10
CV6	Describing objects	9, 10
CV7	Detecting motion	9, 10

Language Interpretation

	Dealing with the complexity of language:	
LI1	Interpreting extended dialogs and text where meaning depends on the context	1-4, 7

LI2	Interpreting indirect or subtle utterances, such as recognizing that "Can you reach the salt" may be a request to pass it	3, 4, 7
	Dealing with imprecision, errors:	
LI3	Interpreting language that is "ungrammatical", e.g., slang or dialect	1-5, 7, 9, 10
LI4	Interpreting uncertain input (e.g., speech)	1-5, 7, 9, 10
LI5	Recognizing continuous speech	1-5, 7, 9, 10

<u>Information Assimilation</u>

	Combining information:	
IA1	From multiple sensors	6-10
IA2	From multiple databases	1, 2, 4, 7
IA3	Combining new information with existing information	7, 10
	Reasoning about the information:	
IA4	Determining that information is lacking	4, 7, 10
IA5	Determining what information to acquire to help establish the certainty of information	3, 4, 7-10
IA6	Combining and reasoning with incomplete and inconsistent information	3, 4, 7-10

<u>Expert Systems</u>

	Acquiring information and/or modifying information	
ES1	Getting the proper information into rules	3, 8
ES2	Extracting and codifying the rules for detecting aircraft handling problems	8
ES3	Methods for easily changing rules	3, 8
	Representing information	
ES4	Representing information about how an aircraft works for use in monitoring and diagnosing problems	8
ES5	Representing the actions required for flying an aircraft	8

ES6	Representing basic repair actions for use by the repair advisor	3
ES7	Encoding information in the repair manual so it can be used by the repair advisor	3
	Reasoning:	
ES8	Using causal models in diagnosis	3, 8
ES9	Reasoning with incomplete, uncertain, and possibly conflicting information	3, 8
ES10	Developing general-purpose expert systems that can handle a range of similar problems	3, 8

<u>Action Planning</u>

	Representation and reasoning:	
AP1	Reasoning about alternative actions	2, 6, 7, 10
AP2	Reasoning about actions in different situations	2, 6, 7, 10
AP3	Reasoning about actions with strict time requirements	2, 7, 10
	Evaluating alternatives:	
AP4	Evaluating alternative plans under varying circumstances	2, 6, 7, 10
AP5	Comparing current plans with historical information	2, 7
	Unexpected events:	
AP6	Reasoning fast and efficiently when the situation changes	2, 6, 10
	Applications of planning:	
AP7	Route planning and following	6, 9, 10
AP8	Planning to acquire information	6, 8, 9, 10

<u>Situation Monitoring</u>

	Monitoring plans:	
SM1	Plan-execution monitoring	2, 6, 9 10

SM2	Recognizing if the information obtained has achieved the desired goal	4, 7, 10
SM3	Detecting that goals have been accomplished based on reported actions	2, 7
SM4	Detecting that a planned action has not been successfully executed	2, 6-8, 10
SM5	Real-time interaction between planning and monitoring	2, 8, 10
	Monitoring situations:	
SM6	General situation monitoring	6, 9, 10
SM7	Detecting important changes in a situation	7, 9
	Plan recognition:	
SM8	Inferring a plan based on observations of individual actions	7

5.1.3. Supporting Technologies

During consideration of the examples in Section 4.2, we also identified some critical technologies that are not usually thought to be AI/robotics. These are considered separately here and are identified as supporting technologies. They include such things as materials, power sources, and semiconductor circuits (notably VHSIC). Separating these from AI/robotics is debatable, at least in some cases, for they are clearly necessary components in many AI/robotics applications. Since they are widely recognized as important research topics independent of AI/robotics, they are listed separately. As the importance of AI/robotics increases in the future, some of these supporting technologies, such as semiconductor circuits, will probably develop specialities that will be considered AI/robotics. Supporting technologies (ST) are listed in Table 22.

Table 22

SUPPORTING TECHNOLOGIES

Topic No.	Topic	Example(s) Supported
ST1	Sensors for determining position and orientation in the battlefield	6, 9, 10
ST2	Sensors for detecting nearby (within (approximately 10 m) objects	6, 9, 10
ST3	Solid-state color TV cameras	6, 9, 10
ST4	Voice input with high level noise background	1, 3-5
ST5	Arm, leg, and gripper components	5
ST6	Power supplies: batteries, fuel cells, nuclear generators	6, 9, 10
ST7	Semiconductor circuits such as VHSIC	1-10

5.1.4. System Considerations

Also, some of the research that will be required to realize future Army applications of AI/robotics is broader in scope than any specific application, or cuts across all applications. This includes such things as militarization, modularity, and system integration. Consequently, another list of research topics is identified as "system considerations." These topics support all applications of AI/robotics, and are listed in Table 23.

Table 23

SYSTEM CONSIDERATIONS

Topic No.	Topic
SC1	R&D planning
SC2	Feasibility studies
SC3	Development tools
SC4	System integration--interface standards
SC5	Modularity
SC6	Distributed systems
SC7	Militarization/reliability/maintainability/hardening
SC8	Countermeasures, counter-countermeasures

5.1.5. Research Tasks

Additional details about the research topics are included in Table 24. This table includes, for each research topic:

* Specific Capability Required for Example--The capability necessary before an advanced development (6.3) project could be initiated for the example.
* Estimated Date to Realize Capability--Assumes research starts in FY 1984 and the capability is achieved in the FY stated.
* Estimated Man-Years--Total number of professional man-years required to realize the capability, regardless of sponsor. Some of the required research may be sponsored in the future by non-Army sponsors, including commercial research laboratories. The estimates here include both Army-sponsored and non-Army-sponsored research.
* Estimated Cost--At $124,000 per man-year, plus $20,000 of computer support per man-year.
* Risk--Degree of risk, from low to high, that the required capability can be achieved by date stated and at estimated cost.

THIS PAGE INTENTIONALLY LEFT BLANK

Table 24

RESEARCH TASKS

Topic	Example(s) Supported	Specific Capability for Example	Estimated Date to Capability	Estimated Man-Years	Estimated Cost $M	Risk
FR1	All	General	Ongoing	4/yr	0.6/yr	Low
FR2	All	General	Ongoing	4/yr	0.6/yr	Low
FR3	All	General	Ongoing	4/yr	0.6/yr	Low
FR4	All	General	Ongoing	4/yr	0.6/yr	Low
FR5	All	General	Ongoing	4/yr	0.6/yr	Low
S1	9, 10	Detect tampering or damage	1995	40	5.7	High
S2	10	Test load-bearing capacity of soil	1988	8	1.2	Med
	5	Sense at wrist and fingers of depalletizing arm	1991	15	2.2	Med
S3	9	Determine range of objects under surveillance				
		Passive	1990	25	3.6	Med
	10	Determine river bottom profile	1988	10	1.4	Med
	6	Sensors for locating mines	1988	20	2.9	Med
E1	9	Walk over rough terrain	1998	100	14.4	High

E2	5	Large arm	1984	10	1.4	Low
		Depallet-izing arm	1990	25	3.6	Med
		High-flexibility arm	1995	50	7.2	High
E3	5	Gripper for tank rounds	1990	5	0.7	Med
M1	5	For tank ammo handler	1986	10	1.4	Low
M2	5	Coordinate two arms	1988	10	1.4	Low
M3	5	Pick up rounds	1988	25	3.6	Low-med
M4	5	Limited--with human aid	1990	150	21.5	Med
MC1	6, 9, 10	Limited route planning	1887	15	2.2	Med
MC2	6, 9,	Land	1990	25	1.7	Med
	10	Water	1987	5	0.7	Med
MC3	9, 10	Walking	1995	50	7.2	Med
	8	Flying helicopter	2000	50	7.2	Med-high
MC4	6, 9	Stay on course	1988	50	7.2	Low-med
	10	Stay on course	1993	150	21.6	High
LG1	1, 2, 4 7, 10	Limited	1985	5	0.7	Low
	3, 4	Difficult	1990	50	7.2	Med

LG2	1, 2, 4 10	Limited	1985	2	0.3	Low
	3, 7, 9	Difficult	1990	75	10.8	Low
LG3	1, 2, 4, 7, 9, 10	Limited	1988	20	3.2	Low-med
	3	Difficult	1992	100	14.4	Med
LG4	2	Limited	1988	5	0.7	Low-med
	7	Difficult	1992	50	7.2	Med
LG5	2, 7, 10	Limited	1986	3	0.4	Low
	3	Difficult	1990	50	7.2	Med
CV1	4, 6, 10	Recognize objects	Ongoing	10/yr	1.4/yr	Low-med
CV2	6, 9, 10	General	Ongoing	10/yr	1.4/yr	Med
CV3	6, 9, 10	Navigation	1988-2000, depending on terrain	500	72	Med-high
CV4	9	General plus IFF	2000	500	72	Med-high
	6	Mines	1988	50	7.2	Med-high
	10	Obstacles	1990	200	28.8	Med-high
CV5	6, 9	Objects on ground	1988	30	4.3	Med
	10	In water	1992	75	10.8	Med-high
CV6	9	On land	1995	75	10.8	Med
	10	In water	1995	100	14.4	Med-high
CV7	9	Simple, land	1988	30	4.3	Low-med
	10	Water	1996	75	10.8	Med
LI1	1-4, 7	Written	1988	25	3.6	Low-med

		Spoken	1993	50	7.2	Med
LI2	3, 4	Limited	1990	100	14.4	Med
	7	Analyze intelli-gence reports	2000	200	28.8	Med-high
LI3	1-5, 7, 9, 10	Same in all	1993	150	21.6	Med
LI4	2-4, 7, 9, 10	Would enhance	1990	75	10.8	Med
	1	Speech	1990	75	10.8	Med
LI5	1-5, 7, 9, 10	Limited	1990	100	14.4	Med
IA1	6-10	Varies	1993-2000	100	14.4	Med
IA2	1, 2, 4, 7		1990	50	7.2	Med
IA3	7	General	1992	50	7.2	Med
IA4	7, 10	General	1992	100	14.4	Med
IA5	3, 4, 7-10	General	1995	100	14.4	Med
IA6	3, 4 7-10	General	1992	100	14.4	Med
ES1	3, 8	General	1986	5	0.7	Low-med
ES2	8	For aircraft	1990	25	3.6	Low-med
ES3	3, 8	For different equipment	1987	15	2.2	Med
ES4	8	For fixed-wing	1993	75	10.8	Med
		For helicopter	1998	150	21.6	Med-high

ES5	8	For fixed-wing	1988	25	3.6	Med
		For helicopter	1998	75	10.8	Med-high
ES6	3	Representation of actions	1993	50	7.2	Med
ES7	3	Beyond text in manual	1990	40	5.8	Med
ES8	8	Aircraft	1995	100	14.4	Med-high
	3	Equipment model	1998	150	21.6	Med-high
ES9	3, 8	General	1997	75	10.8	Med
ES10	3, 8	General	1990	50	7.2	Med
AP1	2, 6, 7, 10	General	1985-1994	25	3.6	Med
AP2	6	Navigation and info. gathering	1985	2	0.3	Med
	10		1990	15	2.2	Med
	2		1990	35	5.0	Med-high
	7		1995	70	10.1	Med-high
AP3	10	Fast response	1990	40	5.8	Med
	2, 7	Timing	1998	50	7.2	Med-high
AP4	6	Route	1986	5	0.7	Med
	10	Route plus sensors	1990	25	3.6	Med-high
	2	Tactics	1992	50	7.2	Med-high
	7	Against	1994	75	10.8	Med-high
AP5	2, 7		1990	50	7.2	Med

AP6	2, 6, 7, 10		1990	50	7.2	Med-high
AP7	6, 9	Land	1986	12	1.7	Med
	10	Water	1990	50	7.2	Med
AP8	6, 8, 9, 10		1990	50	7.2	Med-high
SM1	6, 9, 10	Navigation Sensors	1987	20	2.9	Med
	2		1990	70	10.1	Med
SM2	4, 7, 10	Varies	1988-1995	50-100	7.2-14.4	Med
SM3	2, 7		1990	50	7.2	Med
SM4	2, 7, 8, 10		1993	70	10.1	Med-high
SM5	2, 8, 10		1995	75	10.8	Med-high
SM6	9	Recognize intrusions	1992	75	10.8	Med-high
	7	Threat attention allocation	1992	75-100	10.8-14.4	Med-high
SM7	7, 9		1995	100	14.4	Med-high
SM8	7	Inference planning	1995	200	28.8	High
SC1	all	General	Ongoing	2/yr	0.25	Low
SC2	all	General	Ongoing	4/yr	0.5	Low
SC3	all	General	Ongoing	2/yr	0.25	Low
SC4	all	General	Ongoing	2/yr	0.25	Low
SC5	all	General	Ongoing	1/yr	0.12	Low
SC6	all	General	Ongoing	1/yr	0.12	Low
SC7	all	General	Ongoing	2/yr	0.25	Low
SC8	all	General	Ongoing	1/yr	0.12	Low

5.1.6. Summary

Some tentative conclusions can be stated on the basis of the list of research tasks in Table 24. It lists 97 specific research tasks,

EXAMPLES	RESEARCH TASKS											
	Sensing	Effecting	Manipulators	Mobility Control	Language Generation	Computational Vision	Language Interpretation	Information Assimilation	Expert Systems	Action Planning	Situation Monitoring	TOTAL
Division Commander's Quick Data Access					3		4	1				8
Brigade Mission-Planning Aid					5		4	1		6	4	20
Emergency Repair and Maintenance Advisor					4		5	2	7			18
Interrogation Support System					4		5	3			1	13
Tank Ammunition Handler	1	2	4				2					9
Mine Clearer	1			3		5		1		6	1	17
Tactical Threat Projection System					5		5	6		6	6	28
Safe-Return Controller				1				3	8	1	2	15
Light Fighting Sentry	2	1		4	2	6	3	3		2	3	26
River Reconnaissance System	3			4	4	7	3	4		7	4	36
System TOTAL	7	3	4	12	27	18	31	24	15	28	21	

FIGURE 20 EXAMPLES AND RESEARCH

several (four to sixteen) in each of the technology elements (sensing, effecting, manipulators, etc.), plus five fundamental research topics and eight system considerations. Figure 20 shows the number of research tasks in each of the technology elements supporting each of the ten examples. This figure indicates the complexity (and hence risk, to some degree) of the different examples, and also shows which technology elements are more broadly applicable. This figure shows, for example, that the river reconnaissance system requires the largest number (36) of research tasks, and the Division Commander's Quick Data-Access System requires the least (eight). If the other dimension of the figure is considered (the extent to which each technology element is used in support of the ten examples), then the technology elements, in order of most general applicability first, are:

Language interpretation
Action planning
Language generation
Information assimilation
Situation monitoring
Computational vision
Expert systems
Mobility control
Sensing
Manipulators
Effecting.

This ordered list is something to be considered, but is not in itself a meaningful list of priorities. Priorities are discussed in Section 5.2, Developments.

Another tentative conclusion that can be drawn from Table 24 concerns the schedule for potential developments. Of interest is the earliest date when the research tasks would support a development project for each example. Estimates of dates when such projects might start are indicated in Table 25. These dates are, of course, subject to a good deal of uncertainty, or risk, some more than others. (The risk associated with each example will be discussed later.) In general, the dates are far into the future. Only four of the ten examples can be started within the next ten years:

Table 25

ESTIMATED DATE FOR DEVELOPMENT (6.3 and 6.4) STARTS

Division Commander's Quick Data-Access System	1985
Brigade Mission-Planning Aid	1990
Emergency Repair and Maintenance Advisor	1992
Interrogation Support System	1995
Tank Ammunition Handler	1996
Mine Clearer	1990
Tactical Threat Projection System	1998
Safe-Return Controller	1998
Light Fighting Sentry	2000
River Reconnaissance System	2000

Of these, only the first one can be initiated very soon (1985). If the evolutionary versions of the examples (discussed in Section 4.2) are considered, earlier start dates are possible for most of the examples. These are shown in Table 26. Here, developments of six more examples could be started by 1990. One has already started, the version of the Mine Clearer that is teleoperated and employs a line charge. The one-armed Tank Ammunition Handler could also be started now, and the simple database version of the Brigade Mission Planning Aid could be started in 1985.

Table 26

EARLY STARTS

Mine Clearer (teleoperated, line charge)	1984
Tank Ammunition (one arm) handler	1984
Division Commander's Quick Data-Access System	1985
Brigade Mission Planning Aid	1985
Tank Ammunition (two arms) Handler	1989
Emergency Repair and Maintenance Advisor (first vehicle)	1990
River Reconnaissance System (water only)	1990
Light Fighting Sentry (first version)	1993

5.2. Developments

In this section, benefits, costs, and risks of the development and life cycle of each example from Section 4.2 will be considered. These factors are presented to provide useful background information for the decisions that need to be made in the near term for AI/robotics R&D.

The ten examples were chosen to be illustrative, not the "best" of the 100 Army application concepts that were noted in Section 4.1 and described in Appendix A. The evaluation of the examples in this section applies only to the ten examples and does not have general implications for the other 90 concepts.

To consider benefits, costs, and risks, some information developed in Section 4.2 about distribution and some assumptions about schedules are summarized in Table 27.

Table 27

DISTRIBUTION AND DATES FOR EXAMPLES

Example	No. of Units	Year for Completion of Developments (6.4)
1	24	1989
2	72	1994
3	67,400	1996
4	22	2000
5	840	2002
6	44	1996
7	24	2003
8	1,000	2006
9	10,200	2007
10	66	2007

5.2.1. Benefits

The application categories were ranked according to their estimated contributions to combat effectiveness. This yielded the following list of application categories with highest priority (most benefit) first:

Weapons
Information collectors
Planning and monitoring aids
Situation assessment systems
Support systems
Human/equipment interface aids
Handling support systems
System controllers
Expert advisors
Data assimilation and access aids.

Based on this ranking, the ten examples would have the following ranking:

Light Fighting Sentry
River Reconnaissance System
Brigade Mission Planning Aid
Tactical Threat Projection System
Division Commander's Quick Data-Access System
Mine Clearer
Tank Ammunition Handler
Safe-Return Controller
Emergency Repair and Maintenance Advisor
Interrogation Support System.

Another, more methodical estimate of the relative benefits of each of the ten examples was also developed. Benefits, as considered here, are intended to be a measure of the contribution to combat effectiveness of each example, assuming that it were developed to the full capability described previously. Each example can be thought of as multiplying the total Army combat effectiveness by some factor, just as the quality of command and control is believed to provide an effective force multiplier. Ideally, a quantitative factor, or multiplier, would be desired. For example, if quantitative force multipliers were known for helicopters and robot sentries, then the decisions that need to be made about R&D for robot sentries would be much easier. Unfortunately, the complexities of estimating overall combat effectiveness make such factors unattainable, at least in the context of this study.

In estimating the relative benefits of the ten examples, the full capability of each example was assumed, and, in addition, the examples are assumed to be fully distributed. In the case of the robot sentry,

for example, this full distribution is one robot sentry per APC, or 10,200 robot sentries. The cost of the example and the risk associated with it were not considered in estimating the relative benefits.

For each example, a number of kinds of benefits were considered. These included:

* Reduction of casualties (of personnel)
* Reduction of manpower spaces
* Replacement of manpower skills
* Contribution to continuous combat
* Shortening of the time required
* Conservation of resources
* C^3I multiplier
* Contribution to maneuver
* Weapon effectiveness
* Contribution to survivability of forces
* Percentage of forces affected.

Points were estimated for the amount of each kind of benefit for each of the ten examples. Estimates were prepared independently by a number of persons with different military and technical backgrounds. The points for the different kinds of benefits were added, and the totals for the different estimates were averaged to obtain a single benefits measure for each example. The example estimated to have the greatest contribution to combat effectiveness is listed first.

Mine Clearer
Light Fighting Sentry
Brigade Mission Planning Aid
Emergency Repair and Maintenance Advisor
River Reconnaissance System
Tactical Threat Projection System
Tank Ammunition Handler
Safe-Return Controller
Division Commander's Quick Data-Access System
Interrogation Support System.

If the two benefit rankings are combined, the first based on consideration of application categories and the second based on consideration of the examples, the following ranking is obtained:

Light Fighting Sentry
Brigade Mission Planning Aid
Mine Clearer
River Reconnaissance System
Tactical Threat Projection System
Emergency Repair and Maintenance Advisor
Tank Ammunition Handler
Division Commander's Quick Data-Access System
Safe-Return Controller
Interrogation Support System.

This relative ranking cannot be considered quantitative, but does give an approximate measure of relative benefits of the ten examples for the purpose of evaluating the research and development that supports them.

5.2.2. Costs

The estimated life-cycle costs of the ten concepts are presented here. These include the development (6.3 and 6.4) costs, investment costs (procurement, initial training, etc.), and operations and support costs required to equip a 24-division Army with each of the ten conceptual systems for a period of ten years of operation.

All costs are presented in constant FY 1983 dollars.

The life-cycle cost estimates for the ten representative AI/robotics concepts are shown in Table 28. Details of the cost estimates and the costing methodology are provided in Appendix B of this report.

Table 28

LIFE-CYCLE COST SUMMARY FOR TEN CONCEPTS

(costs in thousands of FY83 $)

Example Number	Example Name	No. of Units Required to Equip 24 Divisions	Program 6.3 and 6.4 R&D Cost	Investment Cost	10-Year Operation and Support Costs	Total Life-Cycle Cost
1	Division Commander's Quick Data-Access System	24	2,674	5,424	13,440	21,538
2	Brigade Mission Planning Aid	72	2,350	12,312	61,200	75,862
3	Emergency Repair and Maintenance Advisor	67,400	1,950	4,246,200	2,696,000	6,943,950
4	Interro-gation Support System	22	2,106	2,640	41,140	45,886
5	Tank Ammunition Handler	840	4,350	393,960	327,600	725,910
6	Mine Clearer	44	6,192	32,252	22,880	61,324
7	Tactical Threat Projection System	24	2,922	4,488	11,040	18,450
8	Safe-Return Controller	1,000	5,824	420,000	330,000	755,824

9	Sentry	10,200	6,134	4,743,000	2,754,000	7,503,134
10	River Reconnais-sance System	66	5,828	28,908	73,260	107,996

5.2.3. Risks

A similar subjective estimate of risks was developed for the examples. Questions considered in assessing the risk of each example are:

Can the technical goals be achieved?
Is the estimated cost of R&D sufficient?
Is the time allowed for R&D sufficient?
Will alternate (non-AI/robotics) approaches be found that are better?
Will the need continue?

The estimate yielded the following list, with the example having the least risk at the head of the list.

Division Commander's Quick Data-Access System
Mine Clearer
Emergency Repair and Maintenance Advisor
Brigade Mission Planning Aid
Tank Ammunition Handler
Interrogation Support System
Brigade Mission Planning Aid
Safe-Return Controller
Light Fighting Sentry
River Reconnaissance System

Again, this relative ranking cannot be considered quantitative, but does give an approximate measure of relative risks.

5.2.4. Benefit, Cost, and Risk Summary

The benefits, costs, and risks of the ten examples are summarized in Table 29.

Table 29

SUMMARY OF BENEFITS, COSTS, AND RISKS

BENEFITS

High	Medium	Low
Light Fighting Sentry	River Reconnaissance System	Division Commander's Quick Data-Access System
Brigade Mission Planning Aid	Tactical Threat Projection System	Safe-Return Controller
Mine Clearer	Emergency Repair and Maintenance Advisor	Interrogation Support System
	Tank Ammunition Handler	

COSTS

High	Medium	Low
Light Fighting Sentry	Safe-Return Controller	River Reconnaissance System
Emergency Repair and Maintenance Advisor	Tank Ammunition System	Brigade Mission Planning Aid
		Mine Clearer
		Interrogation Support System
		Division Commander's Quick Data-Access System
		Tactical Threat projection system

RISKS

High	Medium	Low
River Reconnaissance System	Safe-Return Controller	Tank Ammunition Handler
Light Fighting Sentry	Tactical Threat Projection System	Brigade Mission Planning Aid
	Interrogation Support System	Emergency Repair and Maintenance
		Mine Clearer
		Division Commander's Quick Data-Access System

In the case of the high-benefit examples, two, the Mine Clearer and Brigade Mission Planning Aid, are both low cost and low risk. The Light Fighting Sentry is high cost and high risk.

In the case of the medium benefit examples, two, the Tactical Threat Projection System and the Interrogation Support System are low cost and medium risk, whereas the River Reconnaissance System is low cost and high risk. The Tank Ammunition Handler is medium cost and low risk and the Emergency Repair and Maintenance Advisor is high cost and low risk.

In the case of the low benefit examples, the Division Commander's Quick Data-Access System is low cost and low risk, whereas the Safe-Return Controller is medium cost and medium risk.

5.2.5. Early Starts

In addition to the benefits, costs, and risks, the estimated start dates for the examples are also significant. The examples and their evolutionary versions with starting dates before 1990 are:

1	Mine Clearer (teleoperated, line charge)	1984
2	Tank Ammunition Handler (one arm)	1984
3	Brigade Mission Planning (simple database)	1985
4	Division Commander's Quick Data-Access System	1985
5	Tank Ammunition Handler (two arms)	1989

5.2.5.1. Mine Clearer

As already noted, the Mine Clearer appears to have high benefit, low cost, and low risk. The version described as an example was estimated to be ready for development about 1990. The AI/robotics research required is primarily for mine sensing and navigation. Given priority, the research tasks that support these functions might allow development to start earlier than 1990. The research tasks that support the Mine Clearer are:

S3
MC1, 2, 4
CV1-5
IA1
AP1, 2, 4, 6-8

Also, evolutionary versions of the Mine Clearer should be considered. A teleoperated version that employs a line charge is already being developed.

5.2.5.2. Brigade Mission Planning Aid

The Brigade Mission Planning Aid is also high benefit, low cost, and low risk. The research to support the example was estimated to allow development to start about 1990. Higher priority for the supporting research could accelerate that date. The research tasks that support this planning system, and others as well, are:

LG1-5
LI1, 3-5
IA2
AP1-6
SM1, 3-5

Again, development of an evolutionary version, with a simple database and limited capability, could be started with the present technology base. Evolutionary versions of this example are especially attractive because the capabilities can be improved through software upgrades.

5.2.5.3. Tank Ammunition Handler

The Tank Ammunition Handler has medium benefit, medium cost, and low risk. Development of the example, with three arms, was estimated to start in 1996. This late date is on account of the time estimated for research on the high-flexibility arm. The research that supports the Tank Ammunition Handler is:

S2
E2, 3
M1-4
LI3, 5

The critical research tasks are for manipulation, and these could be given higher priority. Two evolutionary versions were noted previously, one with one arm and another with two arms. Development of the one-arm version could be initiated with the present technology base.

5.2.5.4. Division Commander's Quick Data-Access System

Although the Division Commander's Quick Data-Access System was estimated to have low benefit, the capability it provides would be useful in many other command and control settings. Also, it is low cost, low risk, and the only state-of-the-art example. Its development could be started now. Research that supports it can enhance the performance of the system and other applications of the capability through software upgrades. The research tasks are:

LG1-3
LI1, 3-5
IA2

These tasks also support the Brigade Mission Planning Aid.

5.2.6. Longer Range Developments

The Light Fighting Sentry was evaluated as high benefit, high cost, and high risk. The functions of the Light Fighting Sentry supported by research tasks include: mobility, navigation, identification of targets and IFF, planning, and monitoring, all functions useful and important for other applications as well. Development of the Light Fighting Sentry was estimated to start about the year 2000. An evolutionary version, immobile and teleoperated, could be started sooner, about 1993. The research required to support the future development of the Light Fighting Sentry and other applications that require mobility,

navigation, identification of targets and IFF, planning, or monitoring should have high priority in near-term research plans. These research tasks are:

S1, 3
E1
MC1-4
LG2, 3
CV2-7
LI3-5
AP7, 8
SM1, 6, 7

Many of these, e.g., those required for navigation, have already been listed as required for one or more of the early-start developments in Section 5.2.5.

Two medium-benefit examples, the Tactical Threat Projection System and Interrogation Support System, were estimated to have low cost and medium risk. Also, both are longer range, development of the Tactical Threat Projection System estimated to start in 1998 and the Interrogation Support System in 1995. Both depend on successful research and the solution of difficult problems in AI for which little experience exists. Evolutionary versions of these examples appear unlikely. The research is longer range, but potentially important for these examples and other applications.

The River Reconnaissance System, another medium benefit example, was estimated to be low cost, high risk, and the longest range of all the examples. Fortunately, many of the research tasks required for the River Reconnaissance System are also required for other, higher priority examples. The feasibility of the River Reconnaissance System and other long-range applications can be determined more accurately in the future when the research required for the higher-priority examples is further along.

The Emergency Repair and Maintenance Advisor and the Safe-Return Controller, medium benefit and low benefit, respectively, are both examples of expert systems, an advanced and fairly well understood

specialty in AI. However, both of these examples present difficult problems, not well matched to the state-of-the-art in expert systems, and the Emergency Repair and Maintenance Advisor, because of its wide distribution, requires a large investment. Other expert-system applications are probably better matched to the state-of-the-art and are also important for Army combat or combat support.

6. CONCLUSIONS

AI/robotics will significantly enhance the capabilities of the Army.

A unified model of artificial intelligence (AI) and robotics is appropriate for Army R&D plans in AI robotics. The major components of this model include sensing, interpreting, reasoning, generating, and effecting.

The number of potential applications of AI/robotics in Army combat and combat support is large. One hundred concepts for such applications, collected from a variety of sources, have been described and included here.

The 100 concepts divide reasonably into ten categories of applications, based primarily on combat and combat-support functions. These categories are:

- Human/equipment interface aids
- Planning and monitoring aids
- Expert advisors
- Data assimilation and access aids
- Handling support systems
- Support systems
- Situation assessment systems
- System controllers
- Weapons
- Information collectors

A detailed study of an exemplary concept from each of the application categories revealed a number of gaps between current state-of-the-art in AI/robotics and the technology required to realize the application. These technology gaps, or research tasks, provide a basis for a research plan that supports the development of the exemplary concepts and other applications of AI/robotics in Army combat and combat support.

The recommended research consists of fundamental research, specific research tasks, and system considerations. Included in the research plan for AI/robotics are five fundamental research topics, 97 specific research tasks (in sensing, interpreting, reasoning, generating, and effecting), and eight system considerations. In addition, research on some supporting technologies is required.

The examples of applications of AI/robotics to Army combat and combat support were chosen and described in detail to identify the research required to realize future applications of AI/robotics, not necessarily to realize the specific applications. Most of the recommended research tasks support multiple applications, and several common system modules have been identified. These findings verify the general approach taken here, i.e., the use of examples of applications to motivate the research, even when the examples may not be the ones eventually developed.

This study did not evaluate the 100 concepts for applications of AI/robotics that were collected and described in this report, except for a brief evaluation of ten examples. Additional study and evaluation of all of these concepts are needed. Such studies are needed primarily to define better objective applications of AI/robotics to Army combat and combat support, and secondarily to improve the definition of the research plan presented here.

The recommended research plan includes research to obtain information required to make future decisions about research priorities and application objectives.

Most potential applications will require advancement of the technology base (6.1 and 6.2) before advanced development (6.3) of the applications can be started. With the capabilities ascribed to the ten examples, the study estimated that development could be started on only four during the next ten years. Two examples would require deferment of development until the year 2000.

However, early starts for development of AI/robotics applications are possible if applications with less capability, evolutionary versions of the objective applications, are developed. The study identified four such candidate applications that could be developed now, without advancement of the technology base. These candidate applications are:

Mine Clearer
Brigade Mission Planning Aid
Tank Ammunition Handler
Division Commander's Quick Data-Access System

These applications also rank favorably when benefits, costs, and risks are considered. (In the case of the Mine Clearer, development of a teleoperated version employing a line charge has already started.)

Successful future applications of AI/robotics will require the inclusion of system considerations in research plans, such as feasibility studies, development tools, system integration, and modularity. Both hardware and software modules that would be common for a number of applications appear to be possible. Much of the evolution of AI/robotics systems should be possible by means of module replacement, especially by the upgrading of software modules.

Countermeasures and counter-countermeasures should also be included in the research plan as system considerations.

Although some of the examples that were studied are long range, such as the Light Fighting Sentry and River Reconnaissance System, the research that would make these examples possible should be supported because it is addressed to important functions such as mobility, navigation, and identification of targets, that will be vital for many Army applications in the future.

7. RECOMMENDATIONS

The objective of the study reported here is an R&D plan in AI/robotics for Army combat and combat support. This plan was discussed in detail in Section 5 (Section 5.1--Technology Base; Section 5.2--Development), and will not be repeated here, but it is the principal recommendation of the report. It can be summarized as follows:

Technology Base

- Fundamental research--5 ongoing tasks
- Specific research tasks:
  - Sensing--6 tasks
  - Effecting--5 tasks
  - Manipulators--4 tasks
  - Mobility control--7 tasks
  - Language generation--10 tasks
  - Computational vision--12 tasks
  - Language interpretation--8 tasks
  - Information assimilation--6 tasks
  - Expert systems--13 tasks
  - Action planning--16 tasks
  - Situation monitoring--10 tasks
  - Supporting technologies--7 tasks
- System considerations--8 tasks

Development

The report includes detailed descriptions of ten examples, including the dates when advanced development could be initiated for each, an analysis of benefits, costs, and risks for each, and estimated dates for completion of prototype development. However, these specific examples, in general, are not recommended for development. Their development is discussed to motivate the research plan. Deciding what to develop, and when, will require additional study. Nevertheless, some of the examples appear to be promising enough to warrant special attention as candidates for development, since development of

evolutionary versions of them could be initiated with little or no advancement of the present state-of-the-art. These are:

Mine Clearer
Brigade Mission Planning Aid
Tank Ammunition Handler
Division Commander's Quick Data-Access System

Development of the Mine Clearer (a teleoperated version employing a line charge) has already been started by the Army. Plans for it need to be reviewed in the context of the Mine Clearer described in this report. Research tasks that support the Mine Clearer, for navigation and for mine location, should be given priority.

Research that supports the other three candidate applications, for which the development of evolutionary versions could be started now, should receive special attention.

System considerations are also important and should be included in the research plan, including system integration and modularity. Hardware and software modules for AI/robotics applications could be used to upgrade evolutionary versions and to support multiple applications.

BIBLIOGRAPHY

1--GENERAL

1982 Robotics Industry Directory, Robotics Industry Directory, La Canada, California (1982).

Abraham, R. G., R. J. S. Stewart, L. Y. Shum, "State-of-the-Art in Adaptable-Programmable Assembly Systems," Westinghouse R&D Center, published by IFS Publications Ltd., 35-39 High Street, Kempston, Bedford MK42 7BT, England.

Albus, J. S., "Brains, Behavior, and Robotics," BYTE Books, Subsidiary of McGraw-Hill, Peterborough, New Hampshire (1981).

"Assembly Automation," five issues/year, $84.00/year, IFS Publications Ltd., 35-39 High Street, Kempston, Bedford MK42 7BT, England.

"Assembly Engineering," monthly, controlled circulation, Hitchcock Publishing Company, P.O. Box 3001, Hitchcock Building, Wheaton, Illinois 60187.

Barrow, H. G., "Artificial Intelligence: State of the Art," Technical Note 198, Artificial Intelligence Center, SRI International, Menlo Park, California (October 1979).

Binford, T. O., et al., "Exploratory Study of Computer Integrated Assembly Systems," Progress Report 4, STAN-CS-76-568, Stanford University (1 August 1976 to 31 March 1977).

Binford, T. O., Computer Integrated Assembly Systems," Proceedings, NSF Grantees Conference, Stanford University (January 1981).

Brady, M. and R. L. Paul, eds., The International Journal of Robotics Research, quarterly, $45/year, ISSN 078-3649, Cambridge, Massachusetts, MIT Press Journals.

Brooks T. L., "Superman; a System for Supervisory Manipulation and the Study of Human/Computer Interactions," ONR Contract No. N00014-77-C-0256, master's thesis, Man-Machine Systems Laboratory, M.I.T., Cambridge, Massachusetts (1979).

Brown, D. R., "Recommendations for an AI Research Facility at NASA/GSFC," Task 2 Report, Project 2203, SRI International, Menlo Park, California (October 1981).

Bundy, A., Artificial Intelligence: An Introductory Course, North Holland, New York (1978).

Computerized Robots, The State of the Art, Integrated Computer Systems, Inc., Santa Monica California (September 1980).

Duda, R. O., N. J. Nilsson, and B. Raphael, "State of Technology in Artificial Intelligence," in Research Directions in Software Technology, P. Wegner, ed., pp. 729:749, MIT Press, Cambridge, Massachusetts (1979).

Engelberger, J., Robotics in Practice, Management and Applications of Industrial Robots, New York, AMACOM (division of American Management Associations), 328 pp., $39.95 (1981).

Foley, H., "A Preliminary Survey of Artificial Intelligence Machines," SIGART Newsletter, No. 72, pp. 21-28 (July 1980).

General Dynamics Corporation, "ICAM Robotics Applications Guide," Technical Report AFWAL-TR:80-4042, Vol. II, available (single copies only) on written request to Materials Laboratory, Air Force Wright Aeronautical Laboratories, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio 45433.

Goldman, R., "Recent Work with the AL System," Proceedings of the 5th International joint Conference on Artificial Intelligence, pp. 733-735, Cambridge, Massachusetts (22-25 August 1977).

Hnatek, E. R., "Semiconductor Memory Update: DRAMS," Computer Design, Vol. 21, No. 1, pp. 109-120 (January 1982).

"The Industrial Robot," quarterly, $84.00/year, IFS Publications Ltd., 35-39 High Street, Kempston, Bedford MK42 7BT, England.

"Industrial Robots International," monthly, $12.00/copy, Technical Insights, Inc., 158 Linwood Plaza, P.O. Box 1304, Fort Lee, New Jersey 07024.

Latombe, J.-C., and A. Lux, "Intellegence Artificielle et Robotique Industrielle," Le Nouvel Automatisme, No. 6, pp. 37-44 (May 1979), and No. 7, pp. 21-29 (June-July 1979).

Marshall, M., "LISP Computers go Commercial," Electronics, pp. 89-90 (20 November 1980).

McCorduck, P., Machines Who Think, W. H. Freeman and Co., San Francisco, California (1979).

Mujtaba, M. S., "Current Status of the AL Manipulator Programming System," Proceedings Tenth International Symposium on Industrial Robotics, Milan (1980).

Nitzan, D., "Robotic Automation at SRI," Proceedings of MIDCON/79, Chicago, Illinois (November 1979).

Nitzan, D., et al., "Machine Intelligence Research Applied to Industrial Automation," National Science Foundation Grant DAR78-27128, Robotics Department, SRI International, 333 Ravenswood Avenue, Menlo Park, CA, 94025 (November, 1980).

Paul, R. L., Robot Manipulators, Mathematics, Programming, and Control, Cambridge, Massachusetts, M.I.T. Press (1981).

Proceedings, International Conferences on Industrial Robot Technology, 1st through 10th. IFS Publications Ltd., 35-39 High Street, Kempston, Bedford MK42 7BT, England.

Reed, F., "The Robots are Coming, the Robots are Coming," Next, Vol. 1, No. 2, pp. 30-39 (May/June 1980).

"Robotics Age," bimonthly, $15.00/year, Robotics Publishing Corporation, 10049 Commerce Avenue, Tujunga, California 91042.

"Robotics Today," quarterly, $21.00/year, Robotics International of S.M.E., One SME Drive, P.O. Box 930, Dearborn, Michigan 48128.

Smith, D., and D. Miller, "Computing at the Speed of Light," New Scientist, pp. 554-556 (February 21, 1980).

Society of Mechanical Engineers, "Catalog of Users and Suppliers of Industrial Robots," available through Robotics International of SME.

Takase, K., "Skill of Intelligent Robot," IJCAI-79, Tokyo, Japan (1979).

Taulbee, O. E. and S. D. Conte, "Production and Employment of PhDs in Computer Science," Communications of the ACM, Vol. 19, No. 6, pp. 311-313 (June 1976).

Tesar, D., "Trip Report, Visits to Major Research Centers in Robotics in Europe and Russia," Center for Intelligent Machines and Robotics, Department of Mechanical Engineering, University of Florida, Gainesville, Florida (1981).

Turing, A. M., "Intelligent machinery," in Machine Intelligence, Vol. 5, B. Meltzer and D. Michie, eds., Edinburgh University Press, Edinburgh, and American Elsevier, New York (1970). (Written in 1947, but previously unpublished.)

Weintraub, P., "Raising the Robot's I.Q," Discover, Vol. 2, No. 6, pp. 76-80 (June 1981).

"Why Can't a Computer be More Like a Man?," The Economist, Vol. 282, No. 7219, pp. 77-81, (9 January 1982).

Winston, P. H., "The MIT Robot," in Machine Intelligence, Vol. 7, B. Meltzer and D. Michie, eds., Edinburgh University Press, Edinburgh, and American Elsevier Publishing Company, New York (1972).

Winston, P. H., Artificial Intelligence, Addison-Wesley, Reading (1977).

Winston, P. H. and R. H. Brown, Artificial Intelligence: An MIT Perspective, MIT Press, Cambridge, Massachusetts (1979).

2--SENSING & EFFECTING

Baker, H. H., and T. O. Binford, "Depth from Edge and Intensity Based Stereo," Proceedings, 7th International Joint Conference on Artificial Intelligence, Vancouver, British Columbia (August 1981).

Binford, T. O., "Survey of Model-Based Image Analysis Systems," The International Journal of Robotics Research, Vol. 1, No. 1 (Spring 1982).

Boyle, D., "BETA: Basis for a New Sensor Sorter," International Defense Review, pp. 1275-1276 (August 1978).

Dodd, G. G., and L. Rossol, eds., Computer Vision and Sensor-Based Robots, Plenum Publishing Corporation, New York (1979).

Free, J., "New Eyes for Computers: Chips that See," Popular Science, pp. 61-63 (January 1982).

Harmon, L. D., "Touch-Sensing Technology: A Review," Technical Report MSR80-03, Society of Manufacturing Engineers, Dearborn, Michigan (1980).

Hillis, W. D., "Active Touch Sensing," A.I. Memo 629, Cambridge, Massachusetts, M.I.T. Artificial Intelligence Laboratory (April 1981).

Kowel, S. T., "Beyond Optical Imagers: The DEFT Camera," Optical Spectra, pp. 52-56 (July, 1980).

Mamon, G., et al., "Pulsed GaAs Laser Terrain Profiler," Applied Optics, Vol. 17, No. 6, pp. 868-889 (15 March 1978).

Nitzan, D., "Assessment of Robotic Sensors," Proceedings, NSF Robotics Research Workshop, Newport, Rhode Island (15-17 April 1980) (reprints available from Robotics Department, SRI International, 333 Ravenswood Avenue, Menlo Park, California 94025).

Nitzan, D., A. E. Brain, and R. O. Duda, "The Measurement and Use of Registered Reflectance and Range Data in Scene Analysis," Proceedings of the IEEE, Vol. 65, No. 2, pp. 206-220, (February 1977).

Photonics Spectra, Vol. 16, Issue 1, pp. 59-60 (January 1982).

"Sensor Review," quarterly, $84.00/year, IFS Publications Ltd., 35-39 High Street, Kempston, Bedford MK42 7BT, England.

Stucki, P., ed., Advances in Digital Image Processing, Theory, Application, Implementation, Plenum Publishing Corporation, New York (1979).

Sundaram, G. S., "The Position Location Reporting System," International Defense Review, pp. 1297-1301 (October 1981).

"REMBASS: The US Army's New Battlefield Sensor System," International Defense Review, pp. 531-535 (April 1980).

"The USAF'S PLSS Program," International Defense Review, pp. 1440-1441 (September 1979).

Teja, E. R., "Voice Input and Output," EDN (20 November 1979).

Tenenbaum, J. M., "Prospects for Industrial Vision," Robotics Department, SRI International, Menlo Park, California (November 1978).

Trinkhaus, H. P., "METEX and FEREX: State-of-the-art Hand-held Mine Detectors," International Defense Review, pp. 1482-1484 (September 1978).

3—MANIPULATION

Ambler, A.P.A., et al., "A Versatile System for Computer-Controlled Assembly," Artificial Intelligence, Vol. 6, No. 2, pp. 129-156 (Summer 1975).

Bejczy, A., "Sensors, Controls, and Man-Machine Interface for Advanced Teleoperation," Science, M.I.T. Press, Vol. 208, No. 4450, pp. 1327-35 (20 June 1980).

Bolles, R. C. and R. Paul, "The Use of Sensory Feedback in a Programmable Assembly System," Memo CS-396, Computer Science Department, Stanford University (October 1973).

Brady, M., and R. L. Paul, eds., Robot Motion, Planning and Control, Cambridge, Massachusetts, M.I.T. Press (1982).

Feldman, J., et al., "The Use of Vision and Manipulation to Solve the Instant Insanity Puzzle," Proceedings Second International Joint Conference on Artificial Intelligence, pp. 359-364, London, England (1971).

Goldman, R., "Recent Work with the AL System," Proceedings, Fifth International Joint Conference on Artificial Intelligence, pp. 733-735, Cambridge, Massachusetts (22-25 August 1975). Intelligence Laboratory, Stanford University.

Goldman, R. and S. Mujtaba, "AI User's Manual," Artificial Intelligence Laboratory, Stanford University, third edition (December 1981).

Lozano-Perez, T., "The Design of a Mechanical Assembly System," AI-TR-397, Massachusetts Institute of Technology, Cambridge, Massachusetts (December 1976).

Salisbury, J. K. , "Articulated Hands: Force Control and Kinematic Issues," The International Journal of Robotics Research, Vol. 1, No. 1 (Spring 1982).

4--LOCOMOTION

Bradley, C. D. , "Wheels Versus Tracks," Armor, pp. 24-29 (May-June 1981).

Dicker, R. J. L., "MIN -- The Italian Navy's Mine Disposal Vehicle," International Defense Review, pp. 377-378 (March 1980).

Fincher, S. J., "The Control of a Remotely Piloted Helicopter," IEE Colloquium on Control and Application of Remote Piloted Vehicles, London, England (1-8 January 1980).

Heckman, P. J., Jr., "Free-Swimming Submersible Testbed (EAVE WEST)," Technical Report 622, Naval Ocean Systems Center, San Diego, California (15 September 1980).

Hirose, S., and Y. Umetani, "The Synthesis of Basic Motion Regulator System for Quadrupedal Walking Vehicle and Its Experiments," (in Japanese) Transactions of the Society for Instrumentation and Control Engineering, Vol. 16, No. 5, pp. 743-53 (October 1980).

O'Connor, A.J., "Air Cushion Vehicles," Armor, pp. 13-16 (January-February 1979).

Ogorkiewicz, R. M., "Trends in Tank Technology," Armor, pp. 8-14 (July-August 1980).

Orin, D. E., "Supervisory Control of a Multilegged Robot," The International Journal of Robotics Research, Vol. 1, No. 1 (Spring 1982).

Simpkin, BG R., "Closing the Survivability Gap," Armor, pp. 19-24 (November-December 1981).

5--NATURAL LANGUAGE

Appelt, D. E., "Planning Natural Language Utterances to Satisfy Multiple Goals," Ph.D. Dissertation, Stanford University (December 1981).

Gnanamgari, S., "Providing Automatic Graphic Displays through Defaults," Proceedings of the Third National Conference of Canadian Society of Computational Studies of Intelligence (May 1980).

Grosz, B. G., "Research on Natural-Language Processing at SRI," Technical Note 257, Artificial Intelligence Center, SRI International, Menlo Park, California (November 1981).

Haas, N. and G. G. Hendrix, "Machine Learning for Information Management," Technical Note 252, SRI International, Menlo Park, California (1981).

Harris, L. R., "ROBOT: A High Performance Natural Language Processor for Data Base Query," Proceedings of the Fifth International Joint Conference on Artificial Intelligence, MIT, Cambridge, Massachusetts, pp. 903-904 (1977).

Hendrix, G. G., "LIFER: A Natural Language Interface Facility," Technical Note 135, Artificial Intelligence Center, SRI International, Menlo Park, California (1977).

Hendrix, G. G., E. D. Sacerdoti, "Natural-Language Processing Part One: The Field in Perspective," Technical Note 237, Artificial Intelligence Center, SRI International, Menlo Park, California (1981).

Herot, C. F., G. A. Wilson, "Semantics Versus Graphics--To Show or Not to Show," Technical Report CCA-80-09, Computer Corporation of America (March 1980).

Lowerre, B. T., "The HARPY Speech Recognition System," PhD Thesis and Technical Report, Computer Science Department, Carnegie-Mellon University, Pittsburgh, Pennsylvania (1976).

Moore, R. C., "Practical Natural-Language Processing by Computer," Technical Note 251, Artificial Intelligence Center, SRI International, Menlo Park, California (1981).

Robinson, A. E., et al., "Interpreting Natural-Language Utterances in Dialogs About Tasks," Artificial Intelligence Center, Technical Note 210, SRI International, Menlo Park, California (March 1980).

Winograd, T., "Procedures as Representation for Data in a Computer Program for Understanding Natural Language," Technical Report AI TR-17, MIT, Cambridge, Massachusetts (1971). Also published as Understanding Natural Language, Academic Press, New York, New York (1972).

Woods, W. A., R. M. Kaplan, and B. Nash-Webber, "The Lunar Sciences Natural Language System: Final Report," Report No. 2378, Bolt, Beranek, and Newman, Inc., Cambridge, Massachusetts (1972).

6--PLANNING

Daniels, L., "Planning: Modifying Non-Linear Plans," DAI Working Paper 24, University of Edinburgh (December 1977).

Fikes, R. E., "Monitored Execution of Robot Plans Produced by STRIPS," Proceedings of the IFIP Congress, Ljubljana, Yugoslavia (1971).

Fikes, R. E., P. E. Hart, N. J. Nilsson, "Learning and Executing Generalized Robot Plans," Artificial Intelligence, Vol. 3, No. 4, pp. 251-288 (Winter 1972).

Hayes-Roth, B., et al., "Modeling Planning as an Incremental, Opportunistic Process," Proceedings IJCAI--79, pp. 375—383, Tokyo, Japan (August 1979).

Hayes-Roth, B., et al., "Planners' Workbench: A Computer Aid to Re-Planning," P-6688, The Rand Corporation, Santa Monica, California (October 1981).

Nilsson, N. J., "A Hierarchical Robot Planning and Execution System," Artificial Intelligence Center Technical Note 76, SRI International, Menlo Park, California (April 1973).

Robinson, A. E., and D. E. Wilkins, "Representing Knowledge in an Interactive Planner," Proceedings of the First Annual Conference of the AAAI, pp. 148--150, Stanford University (August 1980).

Robinson, A. E., "SPOT: The Application of Artificial Intelligence to Planning Aircraft Movement on a Carrier," (in preparation).

Rosenschein, S. J., "Plan Synthesis: A Logical Perspective," Proceedings of 1981 International Joint Conference on Artificial Intelligence, Vancouver, British Columbia (25-28 August 1981).

Sacerdoti, E., "A Structure for Plans and Behavior," Elsevier, North-Holland, New York (1977).

Stefik, M., Planning With Constraints," Report STAN-CS-80-784, Computer Science Department, Stanford University, Ph.D. Dissertation (1980).

Tate, A., "Generating Project Networks," Proceedings IJCAI--77, pp. 888-893, Cambridge, Massachusetts (August 1977).

Vere, S., "Planning in Time: Windows and Durations for Activities and Goals," Jet Propulsion Laboratory, Pasadena, California (November 1981).

Wilkins, D. E., and A. E. Robinson, "An Interactive Planning System," Artificial Intelligence Center, Technical Note 245, SRI International, Menlo Park, California (July, 1981).

7--EXPERT SYSTEMS

Bennett, J. S., C. R. Hollander, "Dart: An Expert System for Computer Fault Diagnosis," Proceedings Seventh International Joint Conference on Artificial Intelligence, Vancouver, Canada (August 1981).

Duda, R. O., et al., "Development of the PROSPECTOR Consultation System for Mineral Exploration," Final Report, SRI Projects 5821 and 6415, SRI International, Menlo Park, California (October 1978).

Duda, R. O., J. G. Gaschnig, "Knowledge-Based Expert Systems Come of Age," BYTE Publications Inc., Fairchild Camera and Instrument Corp., Palo Alto, California, and SRI International, Menlo Park, California (September 1981).

Feigenbaum, E. A., "The Art of Artificial Intelligence--Themes and Case Studies of Knowledge Engineering," Proc. Conference FIPS, Vol. 47, National Computer Conference, Anaheim, California (5-8 June 1978). Also published in Proceedings of Fifth International Joint Conference on Artificial Intelligence, MIT, Cambridge, Massachusetts, pp. 1014-1029 (1977).

Genesereth, M. R., "The Use of Hierarchical Design Models in the Automated Diagnosis of Computer Systems," HPP-81-20, Stanford University Heuristic Programming Project, Stanford University (December 1981).

Shortliffe, E. H., "Computer-Based Medical Consultations: MYCIN," Elsevier, New York (1976).

Webster, R. and L. Miner, "Expert systems, Programming Problem-Solving", Technology/2, pp. 62-73 (January/February 1982).

Wilczynski, D., "Knowledge Acquisition in the Consul System," USC/Information Sciences Institute, Marina Del Rey, California.
8--REASONING

Brotsky, D., "Program Understanding Through Cliche Recognition," Artificial Intelligence Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Brown, J. S., et al., "SOPHIE: A Sophisticated Instructional Environment for Teaching Electronic Troubleshooting (an Example of CAI in AI)," BBN Report No. 2790, Bolt, Beranek, and Newman, Inc., Cambridge, Massachusetts (March 1974).

Buchanan, B. G. and J. Lederberg, "The Heuristic DENDRAL Program for Explaining Empirical Data," Proceedings IFIP Congress, Vol. 71, Ljubljana, Yugoslavia (1971).

Ejiri, M., et al., "An Intelligent Robot with Cognition and Decision-Making Ability," Proceedings of the Second International Joint Conference on Artificial Intelligence, London, England, pp. 350-358 (1971).

Garvey, T. D., J. D. Lowrance, M. A. Fischler, "An Inference Technique for Integrating Knowledge from Disparate Sources," Proceedings Seventh International Joint Conference on Artificial Intelligence, pp. 319-325, Vancouver, Canada (August 1981).

Rich, C, "Inspection Methods in Programming," AI-TR-604, Massachusetts Institute of Technology, Cambridge, Massachusetts (June 1981).

Sussman, G. J., "Electrical Design: A Problem for Artificial Intelligence Research," Proceedings Fifth International Joint Conference on Artificial Intelligence, Cambridge, Massachusetts, pp. 894-9000 (1977).

9--BASIC RESEARCH ISSUES

Hendrix, G., Encoding Knowledge in Partitioned Networks, Associative Networks--The Representation and Use of Knowledge in Computers, N.V. Findler, ed., Academic Press, New York, New York (1979).

10--VISION

Agin, G. J., "An Experimental Vision System for Industrial Application," Proceedings Fifth International Symposium on Industrial Robots, IIT Research Institute, Chicago, Illinois (September 1975).

Agin, G. J., "Computer Vision Systems for Industrial Inspection and Assembly," Computer Magazine, Carnegie-Mellon University, Pittsburgh, Pennsylvania (May 1980).

Ballard, D. H. and J. Sklansky, "A Ladder-structured decision tree for recognizing tumors in chest radiographs," IEEE Transaction on Computing, Vol. C-25, No. 5, pp. 503-513 (May 1976).

Barrow, H. G., J. M. Tenenbaum, "Recovering Intrinsic Scene Characteristics from Images," in Computer Visual Systems, A. Hansen and E. Riseman, eds., Academic Press (1978). Also published as Technical Note 157, Artificial Intelligence Center, SRI International, Menlo Park, California (April 1978).

Barrow, H. G., J. M. Tenenbaum, "Computational Vision," Proceedings of the IEEE, Vol. 69, No. 5 (May 1981).

Bolles, R. C., "An Overview of Applications of Image Understanding to Industrial Automation," Technical Note 242, Artificial Intelligence Center, SRI International, Menlo Park, California (1981).

Duda, R. O. and P. Hart, Pattern Classification and Scene Analysis, John Wiley and Sons, New York (1973).

Fischler, M. A., "Image Understanding Research and Its Application to Cartography and Computer-Based Analysis of Aerial Imagery," Semiannual Technical Report, Project 1009, SRI International, Menlo Park, California (July 1980).

Fischler, M. A., "Image Understanding Research and Its Application to Cartography and Computer-Based Analysis of Aerial Imagery," Second and Third Semiannual Technical Reports, Project 1009, SRI International, Menlo Park, California (April 1981).

Gleason, G. J., and G. J. Agin, "A Modular Vision System for Sensor-Controlled Manipulation and Inspection," Technical Note 178, Artificial Intelligence Center, SRI International, Menlo Park, California (1977). Also published in Proceedings of the Ninth International Symposium on Industrial Robots, Washington, DC (March 1979).

Horn, B.K.P., "Obtaining Shape from Shading Information," in The Psychology of Computer Vision, P. H. Winston, ed., 115-15, McGraw-Hill, New York, New York (1975).

Li, C. C., A. M. Savol, and C. P. Fong, "An Improved Algorithm for the Detection of Small, Rounded Pneumoconiosis Opacities in Chest X-

Rays," Proceedings IEEE Conference on Pattern Recognition and Image Processing, Chicago, Illinois, pp. 390-395 (May 1978).

Marr, D., "Visual Information Processing: The Structure and Creation of Visual Representations," Massachusetts Institute of Technology, Cambridge, Massachusetts.

Tenenbaum, J. M., "Application of Image Understanding to Cartography: A Survey of Relevant Research and Opportunities," Technical Report on Project 8718, SRI International (December 1980).

Waltz, D. C., "Generating Semantic Descriptions from Drawings of Scenes with Shadows," AI TR-271, Artificial Intelligence Laboratory, MIT, Cambridge, Massachusetts (August 1972). Also published in The Psychology of Computer Vision, P. H. Winston, ed., pp. 1-91, McGraw-Hill Book Company, New York, New York (1975).

Appendix A

APPLICATION CONCEPTS

Appendix A

APPLICATION CONCEPTS

This appendix contains descriptions of the 100 concepts for applications of AI/robotics technology to Army combat and combat support. The derivation of these concepts is described in Section 4.2. The concepts are grouped for convenience in ten application categories described in Section 4.4. The order of concepts and categories is arbitrary; it does not imply anything regarding relative benefits to the Army, or relative difficulty of development.

1. Human/Equipment Interface Aids

a. Speech Command Auditory Display System

This device would be an avionics component for use in Army helicopters. Its purpose would be to reduce needs for visual checks of instruments by pilots in situations where they must concentrate on visual aspects or flying on target engagement. The device would provide an auditory readout of selected instruments (such as altitude, airspeed, rate of descent). The readout would be provided either in response to specific voice query by the pilot or as a notification when readings outside of pilot-preselected boundaries occurred.

b. Voice Helicopter Control System

This device would be a component for use in helicopters to reduce the pilot workload by enabling the pilot to perform selected control operations by voice. Emphasis would be on operation such as switch or instrument settings, or weapon system employment that currently require the pilot to move his hand or use his eyes. The device would be interactive, conversing with the pilot as necessary to assure understanding of instructions and confirming execution.

c. Scene Interpreter/Clarifier

The purpose of this device would be to aid the soldier during periods of both normal and restricted/impaired visibility in the identification of battlefield images or objects. It would be a module that could be attached to, or used in conjunction with, inventory items such as imaging devices. The Scene Interpreter/Clarifier would be able to discern an object or image when it was partially obscured or camouflaged. The soldier would be able to isolate a field in which he wanted to have an image identified, and the module would alert the soldier to potential hazards/impending lethality if present in that field.

d. Multi-Lingual Order Generator

This would be a device for use at brigade and higher headquarters that would produce detailed orders to subordinate units based on input decisions and guidance. Inputs would be in the form of oral instructions, graphic displays, and written material. Outputs would be hard copy graphics and written instructions in one or more languages. Outputs might also be provided in electronic digitized form for automatic electronic transmission.

e. Division Commander's Quick Data-Access System

The Division Commander's Quick Data-Access System (QDAS) would be a briefcase-sized device intended for personal use of Division commanders to quickly obtain information on the status of available resources and limited other situation information from databases. It would include voice and graphic interfaces and could be connected to data lines to provide complete access to available division automated databases, or it could retain key resource information for limited operation in an isolated mode.

2. <u>Planning and Monitoring Aids</u>

a. <u>Mission Execution Monitor</u>

This concept covers computer software to aid division and higher headquarters in monitoring progress on execution of operation plans. The plan would have the form of an activity diagram (e.g., a PERT chart or hierarchical goal structure). The program would keep track of goals currently being worked on, current resource allocations, alternatives in a plan that were still viable, etc. It would display various aspects of the battle plan, warn of problems (such as units too reduced in strength to carry out their next mission), and indicate when all resources for an activity were available.

b. <u>Signal Array Planner</u>

This concept is for an AI planning system to support dynamic planning and decision-making regarding signal arrays (antenna arrays). The system would aid in planning the best signal configurations to support changing command-center locations.

c. <u>Weapon Selection Planner</u>

This concept pertains to AI software that would be used in selecting weapons for employment against identified targets. The software could be incorporated in automated fire direction and control systems. Based on information acquired about the target and known information on the friendly and enemy situation, the system would use resource allocation and other planning techniques to determine which weapons to use and when to use them.

d. <u>Missile Launch Planner/Controller</u>

This system would be an interactive planning system designed to aid in the planning and control of multiple nuclear/conventional missile launches to support operations. The system would be used to plan necessary movements of firing unit modes to provide the best target

coverage, timing of launches, and alternative fire plans. It would be used to monitor execution and aid in rapidly identifying possible corrective actions to unforeseen difficulties.

e. River-Crossing Planner

This AI planning system would be used to aid in the planning of highly complex deliberate river-crossing operations at division and higher levels. The planning aid would treat all aspects of the operation including maneuver, fire support, and logistics. It would also be used to monitor execution and plan corrective action as unforeseen situations developed. Software and any necessary display hardware would be incorporated in the automated C^2 system of the headquarters involved.

f. Covering Force Maneuver Planner

In defensive operations, maneuver of the covering force is a highly complex operation that must be carefully planned and executed in a timely manner. This AI planning system would be designed to assist in planning and control of such operations. It would incorporate consideration of such factors as the terrain to be defended based on enemy action, displacement to other defensive/delaying positions, possible enemy penetrations, and likely attrition. The system would be used to monitor the developing situation and replan as circumstances dictated.

g. ASP Layout Planner

The ASP Layout Planner would be an AI planning system to assist in determining best layouts of ammunition support points. It would be a portable computer-based device that interactively aided in the planning, considering factors such as inventory, terrain, likely demand patterns, safety factors, and likely receipts of shipments.

h. Brigade Mission Planning Aid

The purpose of the Brigade Mission Planning Aid is to provide rapid mission planning and operations assistance to the Brigade Commander and his key staff members in decision/planning/execution during the course of a dynamic battlefield situation. The system would be designed as a self-contained (except power supply) transportable module, suitable for mounting in an APC or fixed facility when available.

i. Soldier's Movement Guide

The Soldier's Movement Guide would be a small portable system that indicates both the immediate direction and overall route a soldier (or small unit) should move in order to reach a pre-designated objective. It would be used primarily for patrol operations. Prior to the movement, it is used to interactively plan a route based on an internal terrain database and input information on the objective and constraints (such as time, enemy positions, and intermediate objectives). During movement, it would be periodically consulted and interactively provided position and situation updating information. It would warn, when necessary, of potential obstacles and hazards to be encountered, and, if deviation from the planned route were necessary, it would be used to quickly plan an alternative route.

j. Nuclear Fire Planner

This AI planning system would be designed for use at Division and Corps levels to aid in preparing nuclear fire plans. It would be capable of considering mission requirements, nuclear target effects, damage limitation constraints, available weapons, troop safety, and collateral damage risks.

3. Expert Advisors

a. Emergency Repair and Maintenance Advisor

The Emergency Repair and Maintenance Advisor (ERMA) would be a small module used by combat or combat-support vehicle crewmen to obtain expert advice on possible ways to repair their equipment in emergency situations. It would be a self-contained hand-held unit, incorporating a microprocessor, input/output devices, and an expert system covering repair possibilities.

b. Missile Launch Trouble Shooter

The Missile Launch Trouble Shooter (MLTS) would be a small computer device containing an expert system to provide advice to PERSHING II missile crews as an aid in overcoming system faults or failures. It would be a modular component used with, and coupled to, the system programmer test station. It would include a microprocessor, audio input, both audio and CRT display output, and software representing the best available trouble-shooting expertise.

c. Combat Vehicle Service and Survival Advisor

This portable device would provide advice to small units or vehicle commanders regarding possible survival actions or sources of support in their immediate vicinity. In addition to a terrain database, it would contain expert systems to advise on possible locations of sources of supply (civilian fuel, food, water) and to advise on evasion and escape actions.

d. EOD Advisor

The EOD Advisor would be a portable device containing an expert system to provide advice on safing/disarming/disposal procedures to EOD personnel. The system would incorporate available expert knowledge on foreign munitions as well as proven EOD approaches, techniques, and safety measures including field expedients.

e. Water Finder

This concept would be a portable device that would provide advice to soldiers on where to look for water in arid areas. It would incorporate an expert system that could provide advice based on inputs regarding terrain description, local plant and animal life, and recent meteorological conditions.

4. Data Assimilation and Access Aids

a. Interrogation Support System

Intelligence units are tasked with an interrogation mission whose success is largely dependent on the timeliness and accuracy of response information. The Interrogation Support System (ISS) would be a portable device designed to provide the trained human interrogator with a tool to assist in and facilitate the rapid and thorough forward exploitation of POW/detainees for Essential Elements of Information (EEI).

b. C^2 Database Query Language

A language designed for discourse with command and control databases, this software component would be user-oriented and would employ applicative-language techniques (as opposed to procedure-oriented language techniques). The component, in conjunction with automated C^2 systems, would simplify database access for humans.

c. Route Planning Aid

This would be a small, hand-held computer device. It would be used by men on foot, tank commanders, helicopter pilots, etc. It would make use of a terrain database to answer questions about proposed travel routes, such as: What will the terrain look like at any point along the route? Where will a particular type of vehicle be visible to the enemy? Does the terrain prevent the enemy from advancing toward me? What is the safest (fastest, etc.) route to an objective? It would accept voice and manual entry, and would provide responses by graphic display.

d. Combat Vehicle C^2

This device would be a computer display system designed as a component for installation on combat vehicles. It would be designed to provide graphic display of up-to-date information on the friendly situation, terrain, and enemy targets to aid the vehicle commander in effective maneuver and firing. The system would integrate and use all available inputs from other systems (such as maneuver elements, fire support elements sensors, position locating system, navigation system) and an internal terrain database to interactively display key information as requested by the vehicle commander.

e. Imagery Interpretation Aid

This system would be able to assist units tasked with imagery intelligence. Based on hard copy imagery, it would be able to automatically register, identify targets of interest, determine coordinates, and perform UTM coordinate conversions.

f. Adaptive Database Reconfiguration System

This concept encompasses techniques and software that could be applied to databases to create an adaptive reconfigurable database organization capable of restructuring itself to provide optimum performance based on actual use.

g. Multi-Sensor Data Assimilator

This concept includes distributed AI computer software intended to aid in the efficient assimilation of data from multiple sensors into a database. It would include processing of data at the sensor and at the database location. At the sensor location, the system would eliminate clutter, and recognize and select needed data to the database, thus reducing communication needs. At the database location, it would deal with conflicting data, maintain an up-to-date world picture, and recognize and prioritize data gaps for sensor coverage.

5. Handling Support Systems

a. Artillery Loader

This system would be mounted on an ammunition supply vehicle; designed to select appropriate rounds desired by a howitzer crew, prepare them for firing by replacing the nose plug with a fuze, and moving them to a rack on the howitzer for final fuze setting/loading/firing by the crew.

b. Tank Ammunition Handler

The Tank Ammunition Handler is a robotic device that is mounted on platforms used to carry tank ammunition. A 2-1/2 ton truck was chosen for this concept. The device is composed of three robotic arms that work in conjunction to remove ammunition from pallets and hand it to a crewman inside the tank for final storage in racks. It performs the operation of cutting bands, opening cannisters, removing the rounds and lifting/moving them to a position from which a single crewmember can handle the final aspect of storage.

c. Tank Gun Loader

The Tank Gun Loader, a component built into a tank, would perform the manual operations of selecting rounds and loading them into the tank main gun. Based on voice instructions of the tank commander, it would remove a round of the proper type from storage racks and load it. After firing, it would remove spent cartridges from the breech. In the event of misfires, it would be capable of executing standard recovery procedures.

d. Contaminated Clothing Handler

This would be a transportable robotic device for use at forward Personnel Decontamination Stations (PDS). At the PDS, the device would be used to collect discarded items of contaminated clothing and load them into sealed containers for later movement to clothing

decontamination facilities. It could also be used in unloading and handling contaminated clothing at rear laundry/decontamination/impregnation facilities.

e. Contaminated Casualty Handler

The Contaminated Casualty Handler would be a transportable robotic device that would be used at forward aid stations to remove contaminated clothing and equipment from injured soldiers who are not capable of helping themselves. The device would also inspect the injured soldier for any remaining contaminated spots once clothing is removed and apply decontaminant to affected skin areas. In the event that contamination on or very near wounds was detected, the device would not attempt decontamination, but would, instead, clearly mark the area and the patient to warn medical personnel of the problem.

f. Cargo Handler

The Cargo Handler would be a component installed on selected general-purpose supply/transport vehicles of combat units. It would be a highly dexterous voice-controlled or teleoperated device that would load/unload mixed supplies on the vehicle.

g. Multi-Purpose Manipulator

This would be a multi-purpose, transportable robotic system that could be quickly programmed for reach, motion, and position to perform a variety of heavy lifting, moving, and placement tasks in forward areas. Examples of such tasks are: moving bridging sections, moving fuel drums, and transferring ammunition.

h. Refueler

This would be a robotic device, mounted on existing or programmed POL bulk delivery vehicles. It would be able to independently locate fuel-filling points on a variety of vehicles, remove the closure, dispense fuel and reclose the filling point.

i. Vehicle Recovery Aid

The Vehicle Recovery Aid would be a semi-autonomous robotic device employed by the crew of a recovery vehicle to attach cables or other devices to the object/vehicle they are attempting to recover. It would be a highly mobile, maneuverable and dexterous system capable of ground movement, climbing on vehicles, and operating in shallow water, mud, or NBC contamination. It would be able to use simple tools to aid in improvised connections.

j. Ammunition Handler

The Ammunition Handler would be a robotic arm device intended for installation on ammunition supply vehicles. It would be capable of loading ammunition onto the vehicle in palletized or loose form, and of unloading or transferring it to other vehicles.

k. Helicopter Missile/Rocket Reloader

This would be a transportable robotic device designed for use at forward area refuel and rearm points. It would rapidly perform the manual operations of selecting, preparing, picking up, moving, and loading rockets or missiles onto helicopters.

l. Nuclear Munition Outloader

The Nuclear Munition Outloader would be a device designed to rapidly perform lifting, moving, and storing tasks in the outload of nuclear munitions from storage igloos to recovery vehicles. The devices would be specifically programmable for the varying content, configuration, and outloading plans of individual igloos. Their programs could be rapidly modified by voice command, if necessary, during an actual outloading. They would be stored in the igloos. In order to perform periodic training, test, and checkout of the systems without moving nuclear munitions, the devices would be periodically moved and used in dummy facilities in outload exercises.

6. Support Systems

a. Vehicle Decontaminator

The Vehicle Decontaminator, a spraying system, would be designed for use with standard liquid decontaminants and existing or planned decontaminant mixing/application devices to speed operations, operate at higher pressures, and reduce personnel involvement. The system employing robotic spray-painting technology, would have selectable programs for different combat vehicles and would be capable of sensing any deviation from standard configuration and modifying its contour motion accordingly.

b. Armor Resupply and Service Vehicle

This vehicle would be designed to perform rapidly the functions of resupply and servicing of tanks. It would store supplies of fuel, ammunition, and other small items such as crew rations, light weapons ammunition, and lubricants. Under general control of its operator, it would perform automatic refueling using a robotic arm/manipulator. It would incorporate a device similar to the Tank Ammunition Handler for loading main-gun ammunition. Small supply items could also be handed to a crewman inside the tank for storage.

c. Line Charge Laver

This system would be a teleoperated vehicle that could project and detonate a line charge as a means of breaching minefields.

d. Semi-Autonomous Assault Raft

A remotely-piloted raft, this system would be capable of transporting vehicles and personnel across water obstacles. One operator, controlling many rafts from a protected near-shore position, would provide general instructions on loading and unloading points, speed, and route, and could, if necessary, correct these instructions en route. Detailed maneuvering and control along the route would be

performed by the system. The system would remember experiences on the first crossing and use them in planning and executing subsequent trips.

e. Air Robotic Platform

This aircraft, an autonomous air platform, would be capable of carrying or mounting various light payloads depending on the desired mission. Either by itself or as a component in other applications, it would be capable of autonomous takeoff, landing, navigation, and flight between specified end points. It would be a small system capable of carrying payloads up to 100 pounds.

f. Ground Robotic Platform

This system would be an autonomous robotic platform, capable of carrying or mounting various light payloads depending upon the desired mission. It could also be used as a component that would provide mobility in other applications. The platform would be capable of autonomous navigation between specified points, as well as following another vehicle. It would be a lightweight vehicle capable of carrying payloads up to 500 pounds.

g. Combat Vehicle--Support Slave

This would be a semiautonomous or teleoperated device that could perform light tasks on the outside of a combat vehicle under general control of the crew inside the vehicle. Carried on the exterior of the vehicle, it would be highly dexterous and capable of moving all over and around the vehicle, and using simple tools. Examples of tasks it might perform are: minor repair, cleaning of vision/sensor ports, limited decontamination, searching for mines, or observing beyond visual obstacles.

h. Combat Porter

A version of the Ground Robotic Platform, this system would be configured for transporting mixed small cargo loads in forward areas.

It could be used in hazardous environments to perform tasks such as ammunition resupply, rations delivery, and casualty evacuation.

i. Mine Emplacer

The Mine Emplacer would autonomously emplace standard-pattern minefields. Based on a plan provided by the user, it would dig probe-sized holes, fuze and arm mines, and emplace and cover them; it would also be capable of self-loading mines from a nearby supply point. It would automatically mark the minefield boundaries in accordance with standard practices and would produce a hard copy detailed map of the actual emplacements.

j. Soldier's Slave

This system would be designed to perform a variety of manipulative labor tasks under the close supervision and control of a soldier. The soldier would exercise control through voice commands, teleoperation, or, when possible, using "show-and-tell" techniques. In hazardous or contaminated environments, voice commands could be transmitted by radio or wire. The system could perform tasks such as lighting, carrying, digging, erecting or adjusting antennas, or performing minor decontamination operations.

k. Reconnaissance Robot

This system would be similar to the Tactical Reconnaissance Robot, but it would be specially equipped to perform engineer reconnaissance functions. Based on mission orders, it would be able to detect and mark minefields, examine bridge structures, and check trafficability of roads or off-road routes. It would have a limited capability for emplacement of explosive charges.

l. Remote Communication Relay

This autonomous, ground mobile system would be designed to provide line-of-sight radio communication relay at a designated location between

separated units. It could be delivered to the general vicinity of the relay point by ground or air delivery.

m. Adaptive Airborne Communication Relay

This system would be an autonomous aerial platform that would adaptively position itself (and change its position) to act as a communication relay. The system would recognize and adapt to propagation medium changes, electronic countermeasures, and line-of-sight restrictions.

n. Smoke Layer

A mobile platform equipped with smoke-generating capabilities, this system would be capable of moving to prespecified positions and emitting smoke on command. It could be used on flanks or forward of an attack and would reposition itself, based on micrometeorological conditions and observations of its emitted smoke, to maintain the desired smoke pattern. Many of the units would be capable of operating cooperatively.

o. Infantry Precursor

The Infantry Precursor would be a semi-autonomous robotic point man for the infantry squad. Its major functions would be to detect and report any enemy presence. It would be capable of returning any enemy fire it drew for a short period of time until the squad could further develop the situation.

p. Armor Precursor

The Armor Precursor, a semi-autonomous armored vehicle, would operate at the head of an advancing armor unit. It would perform observation and reporting functions, and reconnaissance by fire when directed. It would have a limited capability to detect mines.

q. CP Antenna Remoting System

The CP Antenna Remoting System would be a collection of Ground Robotic Platforms configured to transport antenna components, and manipulation robots such as the Soldier's Slave. These components would be controlled by a central control unit operated by a soldier. The system would be designed to erect and connect rapidly all antennas involved with a major communication node (such as a Division headquarters) at a site chosen for its propagation properties and remote from the headquarters elements. In addition to erecting the antennas, the system would be capable of rapidly laying wire connections to the headquarters facilities (possibly distributed in more than one location).

r. Man-Packed Portable Deception System

This system would simulate a squad or platoon in the field, giving as complete a "signature" as possible to the enemy. It would be able to conduct IFF, activate when necessary, and act in an autonomous fashion. That is to say, it could move to a new position at an appropriate time. In addition to deception in conventional situations, this device would have applications in unconventional warfare where a special forces team would penetrate an area and then "buy time" by using such a device.

s. EOD Assistant

The EOD Assistant, a semi-autonomous robot, with a basic understanding of explosive ordnance disposal (EOD) procedures, would perform specific procedures based on general instructions given by EOD personnel from a safe, remote position.

t. Airborne Minefield Detection System

An autonomous airborne device designed to reconnoiter designated areas for the existence of minefields, this system would employ a platform such as the Air Robotic Platform and multiple sensors (such as optical, IR, and electromagnetic). If mines were detected during the

reconnaissance, it would automatically explore the extent of the obstacle and report this information to the using unit.

u. Barrier Emplacement Aid

This system would be a robotic aid for barrier operations (other than minefield emplacement), including the emplacement of barbed wire or other anti-personnel obstacles, and placement/detonation of shaped charges or explosive devices to create obstacles. It would be a semi-autonomous device, similar to the Soldier's Slave, but would be specifically equipped and optimized for these tasks.

v. Remote Adaptive Jamming System

This device would be able to detect, identify, and locate target signals and decide which to jam and when to jam based on a set of standards, and inputs on the tactical situation. The system would select jamming frequencies and times to delay, confuse, and possibly abort enemy operations. It would recognize and not interfere with higher priority signal-intercept operations.

w. Mine Clearer

The Mine Clearer would be an autonomous vehicle designed to aid the combined arms team in breaching minefields of all types. Equipped with sensors and mine neutralizing devices, it would rapidly traverse mined areas, avoiding mines if possible, neutralizing them if necessary, and marking the resulting safe lanes.

7. Situation Assessment System

a. Brigade Situation Analyzer

This concept would be a computer software component intended to aid the brigade commander and staff in rapidly developing or modifying their estimate of the situation when mission orders are received. The system would maintain a database of information on opposing forces, terrain,

and the brigades' strength and deployments. On receipt of orders, information on the mission, weather, forces, adjacent unit missions, and time constraints would be entered. The system would interactively develop an estimate of the situation including analysis of the friendly and enemy situation, mission, terrain, weather, and constraints. It would also provide the commander and staff with assessments of courses of action they proposed.

b. Artillery Movement Assessment System

This concept would be a software component for use in Division and Corps headquarters as an aid in assessing the implications of information on enemy artillery position, activities, and movements. The system would consider this information along with knowledge of enemy doctrine and tactics, recent battle events, and the current friendly and enemy situation. It would produce interpretations of the meaning of detected movements and predict likely movement times and places.

c. Tactical Threat Projection System

The Tactical Threat Projection System (TTPS) would be an AI software component intended for use at Division and higher headquarters. It would be integrated with other automated software and hardware components of the Division headquarters. Based on continuous data inputs on the tactical situation, the TTPS would be able to project and isolate the most probable courses of action of enemy forces, and the manner in which the threat could manifest itself.

d. Super Sextant

This device would be a briefcase-sized device carried on combat and combat-support vehicles, or, if necessary, transported by a soldier. It would use the best information it could obtain to provide the user with an estimate of his current position. Through a combination of internal sensors/communication links and interactive input by the user, it would assess data from active and passive sources such as celestial

observation, positioning systems, and terrain observation, to estimate its position, and associated uncertainty. The system might be used as a component of other AI/robotics devices.

e. Chemical Hazard Warning Analyzer

This would be a component for use with NBC sensors that are capable of providing spectral observation in the infrared, visible, or ultraviolet bands. It would combine such data with internally stored data on terrain, vegetation, and recently observed atmospheric/surface properties in the area of operations. Based on spectroscopic analysis, it would determine whether or not the sensor data implied a hazard. It would be capable of recognizing suspected new contaminants in addition to the normal repertoire of standard agents.

f. Deception Identification System

In Imitative Communications Deception (ICD), an enemy pretends to be a friendly station, transmitting deceptive signals in order to either disrupt operations with false information, or elicit information of intelligence value. This system would be a device for analyzing and assessing transmissions to identify likely ICD employment efforts. The system would use both technical analysis of the signal, and comparison of its information content with known factors to perform such assessments.

8. System Controllers

a. Line-of-Sight Controller

The Line-of-Sight Controller would be a teleoperated device incorporating a forward vision element, a small multi-purpose manipulator, a communication link, and a viewing/operating remote control element to be used in a safe position. It would be used by soldiers to operate line-of-sight weapons or other devices from remote concealed and safe positions.

b. Safe Return Controller

The Safe Return Controller would be an intelligent system that would assume control of an Army helicopter or airplane when the pilot became disabled. The aircraft would be stabilized, would be returned to a predetermined safe altitude, and would be returned to a friendly airfield. The controller could be overruled by the pilot until such time as it again sensed pilot dysfunction. The system, an avionics component, would use information from other aircraft instruments and would employ any available autopilot system as an aid in implementing the actions it might decide to take.

c. Fire Allocation and Control System

The Fire Allocation and Control System would be an autonomous device capable of deciding on appropriate allocations of targets to available weapons and issuing engagement instructions to such weapons. Based on target information from different sources (including humans or other AI/robotics devices), it would consider the situation, available weapon capabilities, and constraints and engagement rules entered for its particular current employment. It would then provide output signals indicating engagement allocations to the system it controlled (including allocation to individual soldiers or robots manning weapons).

d. IFF Module

An AI-based module to handle Identification Friend/Foe (IFF) should be an essential ingredient of many AI/robotics systems, as well as an aid to control operation of nonautomated weapons. Although various versions of the module would be appropriate for different applications, a common approach could be taken. The use of multi-sensor information inputs (such as visual, electromagnetic signatures, IR or UV characteristics, verbal codes, etc.) should be one ingredient of the IFF determination. In addition to the specific signature patterns used in non-AI systems, this module would also consider the current actions of the object in question, and the context of the current situation in

which those actions occur. Output decisions could be either yes/no or probabilistic in nature.

e. Copilot

The Copilot would be an AI/robotics system configured and designed to substitute for a copilot in Army aircraft. It would be employed as a copilot in combat situations when human copilots were not available. Although its' abilities would be less than those of a human copilot, it would be able to perform most copilot functions, including simple flight maneuvers, weapons control, observation, safety activities, and instrument/control observation and setting with some suitable degree of skill. It would be capable of voice communication with the pilot.

f. Armor Hit Avoidance System

This system would integrate control of available sensors and hit-avoidance devices or procedures on armor vehicles. It might use passive or active sensors to detect threats, and passive or active countermeasures (such as multi-spectral screening smoke) to avoid hits. The system would integrate sensor information with knowledge of the vehicles current situation to promptly recommend (or automatically initiate) survival countermeasures or procedures.

g. Helicopter Automatic Target Acquisition System

The Helicopter Automatic Target Acquisition System would be an AI software module designed to provide rapid sensor data processing and decision functions. It would be integrated with advanced sensor/threat warning components in Army helicopters. The system would perform multi-sensor integration, IFF, and threat prioritization functions. It would base its output recommendations (or automatic decisions) on specific sensor information and knowledge of the aircraft's current situation.

h. <u>EW Equipment Controller</u>

Intelligence units require that electronic equipment be monitored particularly in regard to EW and intercept missions. This includes the continuous monitoring of scopes (regardless of the environment), a 24-hour-a-day tedious task, as an example. The EW Equipment Controller would be a component with necessary electronic interfaces to perform such monitoring tasks, and perform associated responsive equipment control.

i. <u>Communication Network Manager</u>

This system would be a component of communications systems. It applies AI techniques to network management functions such as routing, connectivity assessment, user authentication, and overall system control.

j. <u>Adaptive EW Control System</u>

This system would be a central component used to adaptively control the EW assets at division or higher level. Based on EW support plans, the system would use existing and planned sensors to intercept, locate, and identify enemy electronic emissions. Once interception was accomplished, it would make target decisions based on the current overall situation, such as whether to continue intercept, jam or employ ICD. The decision would involve any desired level of human participation. Based on the decisions the system would provide appropriate control instructions to other EW systems designed to accomplish the actions involved.

k. <u>Target Acquisition and Homing Device</u>

A small component for integration in smart (brilliant) munitions, this device would apply AI techniques to the processing of inputs from one or more on-board sensors. It would be able to identify targets of the desired type in an area and provide sensor control signals and homing signals for terminal guidance. It would incorporate an IFF

module and would allow for imperfect sensor information arising from factors such as smoke, camouflage, or electronic countermeasures.

1. Target Acquisition/Allocation System

This concept would provide an AI-based component for use in automating the target-acquisition and fire-control functions of weapon systems or other AI/robotics devices. Employing available sensors, it would locate and identify targets of the types specified in its instructions and would provide sensor control to optimally support this process. It would perform the IFF function and employ AI planning techniques to create engagement plans best suited to the overall goals of the current operation. Consistent with these plans, it would allocate the targets to weapons for engagement. It would continuously monitor execution and modify plans as new targets/threats emerged.

9. Weapons

a. Tears/Demons

Tank Effectiveness Augmentation by Remote Subsystems (TEARS) is a concept that has been studied extensively by RAND Corporation. This particular application involves augmenting a tank's basic capabilities with one (or more) small semiautonomous mobile subsystem equipped with sensors and an anti-tank weapon (DEMONS). The DEMONS would be controlled from the tank, but data link requirements would be curtailed by allowing some degree of autonomy in the DEMONS operation.

b. Light Fighting Sentry

The Light Fighting Sentry would be a device that could augment the front line combat unit by providing sentry functions. It would carry sensors and weapons and would be armed with a 7.62 mm rifle and a grenade launcher (such as the M 79). Its primary mission would be that of providing sentry-type functions such as warning, overwatch, or covering of obstacles. It would have the capability to engage enemy troops for a short period. In the context of the air-land battle 2000,

the Light Fighting Sentry could aid in providing 360-degree sentry functions to the independent combat team.

c. Heavy Fighting Sentry

The Heavy Fighting Sentry would be conceptually similar to the Light Fighting Sentry; however, it would be equipped with appropriate sensors and weapons to engage enemy armor as well as light weapons for close-in self defense against troops. Emplaced during defensive operations overwatching a likely enemy avenue of approach, it would be trained to occupy several firing positions. Upon sensing enemy armor targets, it would occupy the most effective position and engage the target. During engagement, it might change its position as necessary.

d. Close Air Defense Sentry

The Close Air Defense Sentry would be a system designed to employ light anti-aircraft weapons such as the REDEYE or STINGER automatically against enemy fixed-wing aircraft or helicopters. It might be emplaced on a vehicle during movement or on a position suitable for good aerial observation when stationary. It could be led to its desired position by a soldier and instructed on appropriate observation/engagement sectors. It would incorporate necessary sensors and an IFF module to allow automatic target acquisition and engagement.

e. Infantry Robotic Grenade

The Infantry Robotic Grenade would be a munition similar in size and function to a CLAYMORE mine but designed for use by the infantryman, primarily in the offense. Based on brief instructions from the soldier, it would move rapidly on the ground, autonomously planning its route to a designated point, and then would detonate its directed, fragmentation payload.

f. Homing Tank Killer

The Homing Tank Killer would be a shaped-charge munition designed for employment by the infantryman in close-in defense against advancing enemy armor. Based on brief instructions from the soldier on the general direction and nature of the target, it would autonomously plan a route to engage the advancing tank. It would move rapidly along this ground route, employing a combination of sensors to identify and home on the target. When it reached the target, it would project itself onto the tank in an appropriate position and detonate its shaped charge. It would incorporate a delayed, self-activating mode of operation so that a collection of the munitions could be left to autonomously guard an avenue of approach well forward of the defensive position.

10. Information Collectors

a. River Reconnaissance System

The River Reconnaissance System, a man-portable robotic device, would be used for reconnaissance of water obstacles; it would obtain updated, detailed information on bank conditions, bottom conditions, depths, current profiles, and submerged obstacles in support of planning for hasty or deliberate crossing operations. In offensive situations, it would collect the information needed to select crossing sites and plan crossings which might employ fording vehicles, assault boats, rafts or bridges. In defensive situations, it would provide similar information for use in assessing feasibility of enemy crossings and avenues of approach.

b. NBC Reconnaissance Robot

The NBC Reconnaissance Robot would be an autonomous system designed to perform the function of detecting, identifying, mapping, reporting, marking, and, (if necessary), sampling surface nuclear, biological or chemical contamination. The robot, incorporating both remote and point NBC sensors, would operate in contaminated areas, detect self-contamination, and, upon leaving the areas, would decontaminate itself.

AD-A118 297   SRI INTERNATIONAL MENLO PARK CA   F/G 6/4
R&D PLAN FOR ARMY APPLICATIONS OF AI/ROBOTICS.(U)
MAY 82   D R BROWN, D V FOWLER, D J FRIE   DAAK70-81-C-0250
UNCLASSIFIED   ETL-0296   NL

4 of 4
AD
A118297

END
DATE
FILMED
09-82
DTIC

c. Aerial Observer/Designator

This system would be a semi-autonomous air vehicle that could observe enemy activity, detect and identify targets, and, on command, designate targets with a laser. It would be operated by a person from a concealed position.

The operator would provide instructions on the general area to be observed and a permissible flight envelope for the type of targets sought. Within those constraints, the system would plan and perform its own flight maneuvers to cover the desired area. When a target was acquired, the system would notify the operator and designate/illuminate the target on command for attack with homing munitions.

d. Ground Observer/Designator

Ground Observer/Designator is a semi-autonomous system designed to observe a specified area, alert the user when targets of a specified nature appear, and, on command, designate/illuminate the target with a laser for attack with homing munitions. The system can independently alter its position among preselected alternates to enhance its observation capability and survivability. It normally operates in a passive mode, and transmits a minimum amount of target information only when a target is acquired.

e. Remote Scene Analyzer

This device would be a component for use with imaging sensors such as night-vision devices. Used to analyze the scene observed by the sensor, identify objects in predetermined classes, although they might be partially obscured, and locate the object in terms of its own position, it could operate in either a direct or remote mode; in the direct mode, it would highlight/enhance and identify the object in a visual display for the user. In a remote mode, it would either perform this same function or simply transmit limited data on the object and its location, depending on the user's desires.

f. EW Sentry

This system, a semi-autonomous mobile device equipped with a suite of EW sensors, would be capable of movement to or between predesignated positions where its sensors could be most effectively employed. It would monitor the designated area for any active EW employment indication and transmit positive identification information to its user.

g. NBC Sentry

A mobile device, the NBC Sentry would employ a combination of remote and point NBC detection devices to detect vapor or aerosol NBC contamination, and to automatically transmit warnings to threatened units. It would incorporate a local micro-meteorological measurement and prediction system and a terrain data base. It would select for and adjust its observation position based on observed and predicted conditions in order to provide area coverage and could operate in cooperation with one or more other similar units.

h. Wire Tapper

This device would find enemy wire communication lines, attach itself in a manner suitable for intercepting traffic on the lines, and transmit the intercepted traffic to the using unit. A small rugged device, it could be dispersed behind enemy lines by artillery, rockets, mortars, or aircraft dispensers. It would search for wires employing a combination of electromagnetic, visual and metal sensors. It would include an optional feature to cut detected lines.

i. Street Walker Scout

This system for scouting ahead of Army units fighting in built-up areas would be semi-autonomous, with some control exercised over a wire or other data link. It would be capable of operating up to one block forward of the using unit. In addition to transmitting information from its sensors, it would automatically seek to locate any source of enemy weapons fire.

j. Approach Sentry

This system would be designed to operate as an unattended sentry in forward or rear areas, its primary function being to detect and report the presence of personnel or vehicles within its assigned observation area. It would be capable of observing from fixed positions or along a designated patrol route. It would include optional features that would actively attempt to identify any personnel or vehicles detected.

k. Leach Armor Marker

This device would be a small, low-cost sensor/designator, designed for scattering on likely armor approaches. It would detect and identify any targets of the pre-designated type in its immediate vicinity. It would then attach itself firmly to the target and emit an appropriate signal for homing munitions.

l. Multi-Purpose Sensor Emplacer

This device would be a highly mobile carrier, with a manipulating arm, that would be used to transport a wide variety of sensors to remote positions in the friendly area or behind enemy lines. It would be capable of autonomous route planning navigation, movement and emplacement actions based on brief instructions on objectives from the user.

m. Tactical Reconnaissance Robot

This system would be capable of performing autonomous reconnaissance missions behind enemy lines and planning its detailed activities en route and at specified objectives in order to accomplish its mission. Capabilities would include observation, small object collection, and reconnaissance by fire.

n. Soldier's Auxiliary Eye

The Soldier's Auxiliary Eye would be a small, portable imaging sensor device that would operate selectably in either the visible or the IR bands. It would automatically convert IR-image information to visible displays which could be readily interpreted by the soldier. The device would be remotely controlled and could move short distances on the ground in the vicinity of its operator to reach suitable observation positions.

Appendix B

DETAILS OF COST ANALYSES

Appendix B

DETAILS OF COST ANALYSES

1. Costing Methodology

The representative AI/robotics systems, for which life-cycle cost estimates were generated, were conceptual in nature; the scope of the project did not permit the project team to complete detailed designs for each system, which would have included quantitative, reliable data on system size, weight, power requirements, power output, reliability, maintainability, etc. Consequently, the cost estimates had to be generated with substantial use of qualitative considerations and engineering judgment. In some cases a system element could be considered analogous to an item in the current state-of-the-art; for example, the articulated legs of the light-fighting sentries resemble the industrial robotic arms that are currently available "off-the-shelf" from many manufacturers. In this case, the cost of a sentry leg was assumed to be the same as the cost of a robotic arm, less its programming system (which would be replaced by the sentry's robust computer).

Each of the ten concepts included a high-capacity computer, and this element was, in most cases, a substantial contributor to the total cost of the system; however, it was difficult to predict accurately the costs of these computers because we were looking at a time-frame some years into the future, and the current explosively rapid developments in solid-state technology are very difficult to extrapolate. Essentially, our concepts envisioned miniaturized computers of high capacity, equivalent to the current DEC VAX-11/780. The VAX currently costs about $140,000 to acquire, and it fills a small room. Our concepts envision computers of similar capacity that might fit into a small device like the man-portable River Reconnaissance System. In the cost analysis we

estimated that this super-miniaturized VAX might cost up to $20,000 to acquire, and each concept that required a high-capacity computer was therefore charged $20,000 for its computer. Some of the concepts which presented a lower-capacity computation requirement were charged lesser amounts on the basis of our engineering judgment; for example, $10,000 was charged for the computer in the tank ammunition handler.

The costs of operations and maintenance personnel were based on the assumption that all such personnel were at the E-4 grade level.

To help in the cost analysis, we initiated a mail survey to some 85 current manufacturers of AI and robotics systems, and received approximately a 60 percent response.

In assessing the life-cycle costs of each concept, it was necessary to estimate the number of units of each machine that would be required to equip the whole U.S. Army. To do this, we assumed the Army to be comprised of 24 Divisions[8]* as follows:

6 armored
6 mechanized
10 infantry
1 airborne
1 air assault

The number of units of each system concept was derived from the above Army structure and from the organizational distribution for that concept envisioned by the project team, as shown in Table B-1.

---

* Numbers in parentheses denote references listed at the end of this section.

Table B-1

DERIVATION OF SYSTEM QUANTITY REQUIREMENTS

Concept	Organizational Distribution	Number of Organization Units*	Number of Systems Required
Light Fighting Sentry	1 per APC	10200 APCs	10200
Mine Clearer	2 per engineer battalion	22 battalions	44
River Reconnaissance System	3 per engineer battalion	22 battalions	66
Tank Ammunition Handler	1 per tank ammunition carrier	840 carriers	840
Safe Return Controller	1 per combat aircraft	1000 aircraft	1000
Brigade Mission Planning Aid	1 per brigade	72 brigades	72
Emergency Repair and Maintenance Advisor	1 per vehicle	67400 vehicles	67400
Tactical Threat Projection System	1 per Division	24 Divisions	24
Interrogation Support System	1 per CEWI Battalion	22 CEWI Battalions	22
Division Commander's Quick Data-Access System	1 per Division	24 Divisions	24

Sources: References 8, 18, 19, 20, 21, 22, 23.

*Approximations based on available data regarding Army organizations in transition.

The following sections show the detailed costs of each of the ten concepts we considered. In each case, the sources of our cost estimates are noted to provide the reader an effective audit trail. All costs are in constant FY 1983 dollars.

1 LIGHT FIGHTING SENTRY

Unit Investment Cost

Prime Mission Equipment (PME)	Cost Factor	FY83 $
Hull	40 lbs @ $200[2,3]	$ 8,000
Legs, articulated	4 @ $20,000[10]	80,000
Telescoping mast		20,598[4]
Fuel cell and accessories		5,000[1]
Oxygen generator		5,000[1]
M79 grenade launcher		100[4]
Computer/control panel/display		20,000[1,15,16]
Passive sensors:		
Image analyzer		3,900[14]
IR cameras	2 @ $16,000[4]	32,000
Chemical agent alarm		2,450[4]
Anti-intrusion alarm		1,534[4]
Sound ranging set		7,344[4]
Radiometer		3,860[4]
Radio communication set		800[4]
Voice command input		2,360[12]
Assembly and checkout		10,000[1]
Total PME		$202,946

Auxiliary Equipment (at APC)	Cost Factor	FY83 $
Communication receiver		$ 800[4]
Sentry tracker (communications emitter locater)		2,500[4]
Liquid hydrogen resupply		1,000[1]
Total AUX		$ 4,300
Total PME&AUX		$207,246

Life Cycle Costs

R&D (Programs 6.3 and 6.4 only)	Cost Factor	FY83 $ (000)
Concept formulation/feasibility study	2 MY[1] @ $124K[7]	$ 248
Design	4 MY	496
Test article fabrication	8 @ $203K	1,624
Developmental testing	2 MY	248
Prototype fabrication	1 @ $203K	203
Software R&D	3 MY	372
System integration/test	5 MY	620
Program management	4 MY	496
Data	9 X PME Unit Cost[7]	1,827
Total R&D		$ 6,134

Investment/Unit	Cost Factor	FY83 $ (000)
Prime mission equipment (PME)	(see unit costs)	$ 203
Auxiliary equipment	(see unit costs)	4
Initial training	1 man @ $7,662[7]	8
Test and support equipment	0.2 (PME+AUX)[7]	41
Contractor technical support	0.07 (PME+AUX)[7]	14
Initial spares	0.85 (PME+AUX)[7]	176
Initial transportation	0.09 (PME+AUX)[7]	19
Total Investment/unit		$ 465

Operations and Support/Unit	Cost Factor	FY83 $ (000)
Replacement spares	0.07 (PME+AUX))[7]	$ 14
Depot maintenance	0.025 (PME+AUX))[7]	5
Training of personnel	1 man @ $7,662[7]	8
Total Annual Operations and Support		$ 27

Summary Life Cycle Costs (10 year operational life)[7]	Cost Factor	FY83 $ (000)
R&D		$ 6,134
Investment	10,200 units[8] @ $465K	4,743,000
Operations and Support	10,200units @ $27K X 10 years	2,754,000
TOTAL		$7,503,134

2 MINE CLEARER

Unit Investment Cost

Prime Mission Equipment (PME)	Cost Factor	FY83 $
Frame		$ 4,000[1]
Blast shields	2 @ $4,000[1]	8,000
Mine detection system		
Magnetic sensors	8 @ $272[4]	2,172
IR cameras	2 @ $16,000[4]	32,000
Image analyzer		3,900[14]
Propulsion, 200 hp, with transmission		15,000[1]
Mine demolition unit		8,000[1]
Blastproof rollers	2 @ $8,000[1]	16,000
Computer, memory, display		15,000[1,15,16]
Minefield marker set		1,850[4]
Passive navigation set, inertial		104,000[6]
Assembly and checkout		10,000[1]
Total PME		$219,922

Auxiliary Equipment (AUX)	Cost Factor	FY83 $
Truck, 10 ton		$105,052[11]
Total AUX		$105,052
Total PME&AUX		$324,974

Life Cycle Costs

R&D (Programs 6.3 and 6.4 only)	Cost Factor	FY83 $ (000)
Concept formulation/feasibility study	1 MY[1] @ $124K[7]	$ 124
Design	2 MY	248
Test article fabrication	8 @ $220K	1,760
Developmental testing	1 MY	124
Prototype fabrication	1 @ $220K	220
Software R&D	5 MY	620
System integration/test	5 MY	620
Program management	4 MY	496
Data	9 X PME Unit Cost[7]	1,980
Total R&D		$ 6,192

Investment/Unit	Cost Factor	FY83 $ (000)
Prime mission equipment (PME)	(see unit costs)	$ 220
Auxiliary equipment	(see unit costs)	105
Initial training	2 men @ $7,662[7]	15
Test and support equipment	0.2 (PME+AUX)[7]	65
Contractor technical support	0.07 (PME+AUX)[7]	23
Initial spares	0.85 (PME+AUX)[7]	276
Initial transportation	0.09 (PME+AUX)[7]	29
Total Investment/unit		$ 733

Operations and Support/Unit	Cost Factor	FY83 $ (000)
Truck, 10 ton		$ 16[11]
Replacement spares	0.07 (PME)[7]	15
Depot maintenance	0.025 (PME)[7]	6
Training of personnel	2 men @ $7,662[7]	15
Total Annual Operations and Support		$ 52

Summary Life Cycle Costs (10 year operational life)[7]	Cost Factor	FY83 $ (000)
R&D		$ 6,192
Investment	44 units @ $733K	32,252
Operations and Support	44 units @ $52K X 10 years	22,880
TOTAL		$ 61,324

3 RIVER RECONNAISSANCE SYSTEM

Unit Investment Cost

Prime Mission Equipment (PME)	Cost Factor	FY83 $
Hull segments (6)	20 lbs @ $200[2,3]	$ 4,000
Drive wheels, motorized	5 @ $1,000[1]	5,000
Powered joints	5 @ $1,000[1]	5,000
Powered cowlings	4 @ $500[1]	2,000
Hydrophone array	10 @ $500[1]	5,000
IR cameras	2 @ $16,000[4]	32,000
Navigation set, inertial		104,000[6]
Computer/memory		20,000[1,15,16]
Fordability tester		4,600[4]
Rechargeable battery		637[6]
Self-leveling optical assembly, automatic		4,250[4]
Assembly and checkout		10,000[1]
Total PME		$186,487

Auxiliary Equipment (AUX)	Cost Factor	FY83 $
Portable I/O unit (for soldier)		$ 5,000[1]
Battery charger/analyzer		975[4]
Total AUX		$ 5,975
Total PME&AUX		$192,462

Life Cycle Costs

R&D (Programs 6.3 and 6.4 only)	Cost Factor	FY83 $ (000)
Concept formulation/feasibility study	2 MY[1] @ $124K[7]	$ 248
Design	4 MY	496
Test article fabrication	8 @ $186K	1,488
Developmental testing	2 MY	248
Prototype fabrication	1 @ $186K	186
Software R&D	3 MY	372
System integration/test	5 MY	620
Program management	4 MY	496
Data	9 X PME Unit Cost[7]	1,674
Total R&D		$ 5,828

Investment/Unit	Cost Factor	FY83 $ (000)
Prime mission equipment (PME)	(see unit costs)	$ 186
Auxiliary equipment	(see unit costs)	6
Initial training	2 men @ $7,662[7]	15
Test and support equipment	0.2 (PME+AUX)[7]	38
Contractor technical support	0.07 (PME+AUX)[7]	13
Initial spares	0.85 (PME+AUX)[7]	163
Initial transportation	0.09 (PME+AUX)[7]	17
Total Investment/unit		$ 438

Operations and Support/Unit	Cost Factor	FY83 $ (000)
Military personnel	2 men @ $29,817[7]	$ 60
Replacement spares	0.07 (PME+AUX)[7]	13
Depot maintenance	0.025 (PME+AUX)[7]	5
PCS travel	2 men @ $1,048[7]	2
Training of other personnel	4 men @ $7,662[7]	31
Total Annual Operations and Support		$ 111

Summary Life Cycle Costs (10 year operational life)[7]	Cost Factor	FY83 $ (000)
R&D		$ 5,828
Investment	66 units @ $438K	28,908
Operations and Support	66 units @ $111K X 10 years	73,260
TOTAL		$107,996

4 TANK AMMUNITION HANDLER

Unit Investment Cost

Prime Mission Equipment (PME)	Cost Factor	FY83 $
High flexibility arm, with programmer		$ 33,000[10]
Loading arm, with programmer		33,000[10]
Depalletizing arm, with programmer		33,000[10]
Round identifier		30,000[17]
Communication set		800[4]
Generator set, 45 kw		16,105[4]
Computer		10,000[1,15,16]
Assembly and checkout		10,000[1]
Total PME		$165,905

Auxiliary Equipment (AUX)	Cost Factor	FY83 $
Truck, 2 1/2 ton		$ 42,461[11]
Total AUX		$ 42,461
Total PME&AUX		$208,366

Life Cycle Costs

R&D (Programs 6.3 and 6.4 only)	Cost Factor	FY83 $ (000)
Concept formulation/feasibility study	1 MY[1] @ $124K[7]	$ 124
Design	2 MY	248
Test article fabrication	5 @ $166K	830
Developmental testing	1 MY	124
Prototype fabrication	1 @ $166K	166
Software R&D	2 MY	248
System integration/test	5 MY	620
Program management	4 MY	496
Data	9 X PME Unit Cost[7]	1,494
Total R&D		$ 4,350

Investment/Unit	Cost Factor	FY83 $ (000)
Prime mission equipment (PME)	(see unit costs)	$ 166
Auxiliary equipment	(see unit costs)	42
Initial training	1 man @ $7,662[7]	8
Test and support equipment	0.2 (PME+AUX)[7]	42
Contractor technical support	0.07 (PME+AUX)[7]	15
Initial spares	0.85 (PME+AUX)[7]	177
Initial transportation	0.09 (PME+AUX)[7]	19
Total Investment/unit		$ 469

Operations and Support/Unit	Cost Factor	FY83 $ (000)
Generator set O&M		$ 7[11]
Truck, 2 1/2 ton		8[11]
Replacement spares	0.07 (PME)[7]	12
Depot maintenance	0.025 (PME)[7]	4
Training of other personnel	1 man @ $7,662[7]	8
Total Annual Operations and Support		$ 39

Summary Life Cycle Costs (10 year operational life)[7]	Cost Factor	FY83 $ (000)
R&D		$ 4,350
Investment	840 units @ $469K	393,960
Operations and Support	840 units @ $39K X 10 years	327,600
TOTAL		$725,910

5 SAFE RETURN CONTROLLER

Unit Investment Cost

Prime Mission Equipment (PME)	Cost Factor	FY83 $
Automatic flight control system		$ 28,000[4]
Navigation set, inertial		104,000[6]
Aircraft/pilot condition analyzer		16,915[4]
Voice output device		995[13]
Voice input device		2,360[12]
Computer/memory		20,000[1,15,16]
Assembly and checkout		10,000[1]
Total PME		$182,270

Auxiliary Equipment (AUX)	Cost Factor	FY83 $
Ground control station at home base		$ 712*
Total AUX		$ 712
Total PME&AUX		$182,982

Life Cycle Costs

R&D (Programs 6.3 and 6.4 only)	Cost Factor	FY83 $ (000)
Concept formulation/feasibility study	1 MY[1] @ $124K[7]	$ 124
Design	2 MY	248
Test article fabrication	8 @ $172K	1,376
Developmental testing	4 MY	496
Prototype fabrication	1 @ $172K	172
Software R&D	6 MY	744
System integration/test	5 MY	620
Program management	4 MY	496
Data	9 X PME Unit Cost[7]	1,638
Total R&D		$ 5,914

---

*This system is estimated to cost $35,603[4] per installation. Assuming one system serves 50 aircraft only 2% of this cost is charged to each Safe Return Controller.

Investment/Unit	Cost Factor	FY83 $ (000)
Prime mission equipment (PME)	(see unit costs)	$ 182
Auxiliary equipment	(see unit costs)	1
Initial training	2 men @ $7,662[7]	15
Test and support equipment	0.2 (PME+AUX)[7]	37
Contractor technical support	0.07 (PME+AUX)[7]	13
Initial spares	0.85 (PME+AUX)[7]	156
Initial transportation	0.09 (PME+AUX)[7]	16
Total Investment/unit		$ 420

Operations and Support/Unit	Cost Factor	FY83 $ (000)
Replacement spares	0.07 (PME+AUX)[7]	$ 13
Depot maintenance	0.025 (PME+AUX)[7]	5
Training of personnel	2 men @ $7,662[7]	15
Total Annual Operations and Support		$ 33

Summary Life Cycle Costs (10 year operational life)[7]	Cost Factor	FY83 $ (000)
R&D		$ 5,824
Investment	1000 units @ $420K	420,000
Operations and Support	1000 units @ $33K X 10 years	330,000
TOTAL		$755,824

6 BRIGADE MISSION PLANNING AID

Unit Investment Cost

Prime Mission Equipment (PME)	Cost Factor	FY83 $
Computer		$ 20,000[1,15,16]
Power supply		400[1]
Voice output device		995[13]
Voice input device		2,360[12]
Hard copy printer		20,000[1,15,16]
Communication links to data bases	5 @ $800[1]	4,000
Assembly and checkout		2,000[1]
Total PME		$ 49,755

Auxiliary Equipment (AUX)	Cost Factor	FY83 $
Truck, 1/4 ton		$ 16,833[11]
Total AUX		$ 16,833
Total PME&AUX		$ 66,588

Life Cycle Costs

R&D (Programs 6.3 and 6.4 only)	Cost Factor	FY83 $ (000)
Concept formulation/feasibility study	0.5 MY[1] @ $124K[7]	$ 62
Design	1 MY	124
Test article fabrication	6 @ $50K	300
Developmental testing	1 MY	124
Prototype fabrication	1 @ $50K	50
Software R&D	5 MY	620
System integration/test	3 MY	372
Program management	2 MY	248
Data	9 X PME Unit Cost[7]	450
Total R&D		$ 2,350

Investment/Unit	Cost Factor	FY83 $ (000)
Prime mission equipment (PME)	(see unit costs)	$ 50
Auxiliary equipment	(see unit costs)	17
Initial training	3 men @ $7,662[7]	23
Test and support equipment	0.2 (PME+AUX)[7]	13
Contractor technical support	0.07 (PME+AUX)[7]	5
Initial spares	0.85 (PME+AUX)[7]	57
Initial transportation	0.09 (PME+AUX)[7]	6
Total Investment/unit		$ 171

Operations and Support/Unit	Cost Factor	FY83 $ (000)
Military personnel	2 men @ $29,817[7]	$ 60
Truck, 1/4 ton		10[11]
Replacement spares	0.07 (PME)[7]	4
Depot maintenance	0.025 (PME)[7]	1
PCS travel	2 men @ $1,048[7]	2
Training of other personnel	1 man @ $7,662[7]	8
Total Annual Operations and Support		$ 85

Summary Life Cycle Costs (10 year operational life)[7]	Cost Factor	FY83 $ (000)
R&D		$ 2,350
Investment	72 units @ $171K	12,312
Operations and Support	72 units @ $83K X 10 years	61,200
TOTAL		$ 75,862

7 EMERGENCY REPAIR AND MAINTENANCE ADVISOR (ERMA)

Unit Investment Cost

Prime Mission Equipment (PME)	Cost Factor	FY83 $
Computer/control panel/display		$ 20,000[1,15,16]
Voice output device		995[13]
Voice input device		2,360[12]
Battery power supply		637[6]
Assembly and checkout		1,000[1]
Total PME		$ 24,992

Auxiliary Equipment (AUX)	Cost Factor	FY83 $
Program Change Unit (PCU)	0.05* x 1,000[1]	$ 50
Battery analyzer/charger	0.05 x 975[4]	49
Total AUX		$ 99
Total PME&AUX		$ 25,091

*For 24 Army Divisions, 96 PCUs support 2,100 ERAs or 0.05 PCU per ERA.

Life Cycle Costs

R&D (Programs 6.3 and 6.4 only)	Cost Factor	FY83 $ (000)
Concept formulation/feasibility study	0.5 MY[1] @ $124K[7]	$ 62
Design	1 MY	124
Test article fabrication	6 @ $25K	150
Developmental testing	1 MY	124
Prototype fabrication	1 @ $25K	25
Software R&D	5 MY	620
System integration/test	3 MY	372
Program management	2 MY	248
Data	9 X PME Unit Cost[7]	225
Total R&D		$ 1,950

Investment/Unit	Cost Factor	FY83 $ (000)
Prime mission equipment (PME)	(see unit costs)	$ 25
Auxiliary equipment	(see unit costs)	0
Initial training	1 man @ $7,662[7]	8
Test and support equipment	0.2 (PME+AUX)[7]	5
Contractor technical support	0.07 (PME+AUX)[7]	2
Initial spares	0.85 (PME+AUX)[7]	21
Initial transportation	0.09 (PME+AUX)[7]	2
Total Investment/unit		$ 63

Operations and Support/Unit	Cost Factor	FY83 $ (000)
Replacement spares	0.07 (PME+AUX)[7]	$ 2
Depot maintenance	0.025 (PME+AUX)[7]	1
Training of personnel	1 man @ $1,000[1]	1
Total Annual Operations and Support		$ 4

Summary Life Cycle Costs (10 year operational life)[7]	Cost Factor	FY83 $ (000)
R&D		$ 1,950
Investment	67,400 units @ $63K	4,246,200
Operations and Support	67,400 units @ $4K X 10 years	2,696,000
TOTAL		$6,943,950

8 TACTICAL THREAT PROJECTION SYSTEM

Unit Investment Cost

Prime Mission Equipment (PME)	Cost Factor	FY83 $
Computer/memory		$ 20,000[1,15,16]
Keyboard/CRT color display		25,000[1,15,16]
Power supply		1,000[1]
Hard copy printer		30,000[1,15,16]
Assembly and checkout		2,000[1]
Total PME		$ 78,000

Auxiliary Equipment (AUX)	Cost Factor	FY83 $
None		
Total AUX		$ 0
Total PME&AUX		$ 78,000

Life Cycle Costs

R&D (Programs 6.3 and 6.4 only)	Cost Factor	FY83 $ (000)
Concept formulation/feasibility study	0.5 MY[1] @ $124K[7]	$ 62
Design	1 MY	124
Test article fabrication	6 @ $78K	468
Developmental testing	1 MY	124
Prototype fabrication	1 @ $78K	78
Software R&D	6 MY	744
System integration/test	3 MY	372
Program management	2 MY	248
Data	9 X PME Unit Cost[7]	702
Total R&D		$ 2,922

Investment/Unit	Cost Factor	FY83 $ (000)
Prime mission equipment (PME)	(see unit costs)	$ 78
Auxiliary equipment	(see unit costs)	0
Initial training	2 men @ $7,662[7]	15
Test and support equipment	0.2 (PME+AUX)[7]	16
Contractor technical support	0.07 (PME+AUX)[7]	5
Initial spares	0.85 (PME+AUX)[7]	66
Initial transportation	0.09 (PME+AUX)[7]	7
Total Investment/unit		$ 187

Operations and Support/Unit	Cost Factor	FY83 $ (000)
Military personnel	1 man @ $29,817[7]	$ 30
Replacement spares	0.07 (PME+AUX)[7]	5
Depot maintenance	0.025 (PME+AUX)[7]	2
PCS travel	1 man @ $1,048[7]	1
Training of other personnel	1 man @ $7,662[7]	8
Total Annual Operations and Support		$ 46

Summary Life Cycle Costs (10 year operational life)[7]	Cost Factor	FY83 $ (000)
R&D		$ 2,922
Investment	24 units @ $187K	4,488
Operations and Support	24 units @ $46K X 10 years	11,040
TOTAL		$ 18,450

9 INTERROGATION SUPPORT SYSTEM

Unit Investment Cost

Prime Mission Equipment (PME)	Cost Factor	FY83 $
Computer/control panel/display		$ 20,000[1,15,16]
Power supply		1,000[1]
Hard copy printer, micro		500[1,15,16]
Voice output device		995[13]
Voice input device		2,360[12]
Assembly and checkout		2,000[1]
Total PME		$ 26,855

Auxiliary Equipment (AUX)	Cost Factor	FY83 $
None		
Total AUX		$ 0
Total PME&AUX		$ 26,855

Life Cycle Costs

R&D (Programs 6.3 and 6.4 only)	Cost Factor	FY83 $ (000)
Concept formulation/feasibility study	0.5 MY[1] @ $124K[7]	$ 62
Design	1 MY	124
Test article fabrication	6 @ $27K	162
Developmental testing	1 MY	124
Prototype fabrication	1 @ $27K	27
Software R&D	6 MY	744
System integration/test	3 MY	372
Program management	2 MY	248
Data	9 X PME Unit Cost[7]	243
Total R&D		$ 2,106

Investment/Unit	Cost Factor	FY83 $ (000)
Prime mission equipment (PME)	(see unit costs)	$ 27
Auxiliary equipment	(see unit costs)	0
Initial training	8 men @ $7,662[7]	61
Test and support equipment	0.2 (PME+AUX)[7]	5
Contractor technical support	0.07 (PME+AUX)[7]	2
Initial spares	0.85 (PME+AUX)[7]	23
Initial transportation	0.09 (PME+AUX)[7]	2
Total Investment/unit		$ 120

Operations and Support/Unit	Cost Factor	FY83 $ (000)
Military personnel	1/2 time x 8 men @ $29,817[7]	$ 119
Replacement spares	0.07 (PME+AUX)[7]	2
Depot maintenance	0.025 (PME+AUX)[7]	1
PCS travel	1/2 time x 8 men @ $1,048[7]	4
Training of personnel	8 men @ $7,662[7]	61
Total Annual Operations and Support		$ 187

Summary Life Cycle Costs (10 year operational life)[7]	Cost Factor	FY83 $ (000)
R&D		$ 2,106
Investment	22 units @ $120K	2,640
Operations and Support	22 units @ $187K X 10 years	41,140
TOTAL		$ 45,886

10 DIVISION COMMANDER'S QUICK DATA-ACCESS SYSTEM

Unit Investment Cost

Prime Mission Equipment (PME)	Cost Factor	FY83 $
Computer/control panel		$ 20,000[1,15,16]
Voice input device		2,360[12]
Power supply		1,000[1]
Hard copy printer		30,000[1,15,16]
Color display		25,000[1,15,16]
Assembly and checkout		5,000[1]
Total PME		$ 78,360

Auxiliary Equipment (AUX)	Cost Factor	FY83 $
Truck, 1/4 ton		$ 16,833[11]
Total AUX		$ 16,833
Total PME&AUX		$ 95,193

Life Cycle Costs

R&D (Programs 6.3 and 6.4 only)	Cost Factor	FY83 $ (000)
Concept formulation/feasibility study	0.5 MY[1] @ $124K[7]	$ 62
Design	1 MY	124
Test article fabrication	6 @ $78K	468
Developmental testing	1 MY	124
Prototype fabrication	1 @ $78K	78
Software R&D	4 MY	496
System integration/test	3 MY	372
Program management	2 MY	248
Data	9 X PME Unit Cost[7]	702
Total R&D		$ 2,674

Investment/Unit	Cost Factor	FY83 $ (000)
Prime mission equipment (PME)	(see unit costs)	$ 78
Auxiliary equipment	(see unit costs)	17
Initial training	2 men @ $7,662[7]	15
Test and support equipment	0.2 (PME+AUX)[7]	19
Contractor technical support	0.07 (PME+AUX)[7]	7
Initial spares	0.85 (PME+AUX)[7]	81
Initial transportation	0.09 (PME+AUX)[7]	9
Total Investment/unit		$ 226

Operations and Support/Unit	Cost Factor	FY83 $ (000)
Military personnel	1 man @ $29,817[7]	$ 30
Truck, 1/4 ton		10[11]
Replacement spares	0.07 (PME)[7]	5
Depot maintenance	0.025 (PME)[7]	2
PCS travel	1 man @ $1,048[7]	1
Training of other personnel	1 man @ $7,662[7]	8
Total Annual Operations and Support		$ 56

Summary Life Cycle Costs (10 year operational life)[7]	Cost Factor	FY83 $ (000)
R&D		$ 2,674
Investment	24 units @ $226K	5,424
Operations and Support	24 units @ $56K X 10 years	13,440
TOTAL		$ 21,538

REFERENCES TO APPENDIX B

1. SRI engineering estimate.

2. "U.S. Military Aircraft," Aviation Week and Space Technology, Vol. 114, No. 10, pp. 116-117 (9 March 1981).

3. Cost and Planning Factors Regulation, Air Force Regulation 173-13 (1 February 1981).

4. Army Adopted/Other Selected Items and List of Reportable Items, Army Supply Bulletin, SB 700-20, (1 September 1981).

5. Systems Analysis of Remote Piloting/Robotics Technology Applicable to Assault Rafts, Final Report, Arthur D. Little, Inc. Cambridge, Massachusetts (January 1982).

6. "Advanced Remotely Piloted Vehicle," Appendix D: Life Cycle Cost, System/Subsystem Summary Report, Northrop Corporation, Venture Division, Newbury Park, California (22 April 1976).

7. Defense Communications Agency, Cost and Planning Factor Manual>, DCA Circular 600-60-1 (May 1976, Revised to December 1981).

8. Handbook, Army Reference Data, U.S. Army War College, Carlisle Barracks, Pennsylvania (1978).

9. Logistics Reference Data (formerly NWIP 11-21), NAVMAT P-4000-2, Headquarters Naval Material Command (30 September 1973).

9. Tanner, W. R., ed., Industrial Robots, Volume 1: Fundamentals, Second Edition, pp. 21-26, Robotics International of SME, Dearborne, Michigan (1980).

10. Cost Estimating Handbook (Methods and Factors), U.S. Army Communications Research and Development Command, Fort Monmouth, New Jersey (March 1980).

11. "Price List for Auricle I and Auricle PCB," Threshold Technology Inc. (private communication).

12. Moyna, M., VOTRAX Division of Federal Screw Works (private communication).

13. Baker, R., Director, HVS Image Analyzing (private communication).

14. "DEC VAX 11-780 Management Summary," from DATAPRO Reports on Minicomputers, DATAPRO Research Corporation (April 1980).

15. "3600 Symbol Processing Systems," from Symbolics Inc. price list (April 1981).

16. Cronin, M. J., "Price List for Programmable Visual Inspection System," AUTOVISION II, Automatix, Inc. (February 1981).

17. The Division Field Manual, FM 61-100, Headquarters, Department of the Army (1969).

18. The Battalion Field Manual, Headquarters, Department of the Army (1968).

19. Bigelman, Major P., "Army 86 Blueprint for Tomorrow," Army, pp. 21-42 (June 1981).

20. Organization of Brigade and Battalion Manual, U.S. Army Infantry School, Fort Benning, Georgia (1978).

21. Command and Staff Manual, U.S. Army Infantry School, Fort Benning, Georgia (1978).

22. Infantry Reference Data, Volumes I and II, ST7-157, U.S. Army Infantry School, Fort Benning, Georgia (FY 1975).


FILME